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VESUVIANITE FROM GEORGETOWN, CALIFORNIA

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INTRODUCTION

Within the last year or so crystals of vesuvianite from near Georgetown, El Dorado County, California, have been sold by several mineral dealers. The writer has made two visits to the locality from which these crystals have come and has examined all of the more important veins in which they occur. A grant from the Board of Research of the University of California in support of this work is gratefully acknowledged.

GEOLOGICAL OCCURRENCE

All of the veins lie in a serpentine belt along Traverse Creek about two and a half miles south southeast of Georgetown in the Placerville Quadrangle,¹ California. The veins are near the southern extremity of this serpentine belt where the Bear Creek Road crosses Traverse Creek. The serpentine here is about half a mile wide and is bounded on both sides by amphibolite with minor bodies of schist.

The serpentine is for the most part highly sheared. The shear surfaces, though irregular, tend to follow the regional strike, N-NW. Magnetite and chromite are scattered through the serpentine. A few chromite segregations have yielded small quantities of ore. There are some bands of chlorite.

Several dikes cut the serpentine. Near the eastern contact there is a fresh massive diorite dike several yards thick that may be traced for a few hundred yards. Near the center of the serpentine belt there are a few small aplitic dikes that have been greatly sheared. These are only a foot or two thick and can be traced for only a few yards. One small vein or dike consists of angular fragments of albite up to half an inch long crowded with high index inclusions, possibly epidote, and cemented by clear glassy quartz. None of these dikes come in contact with the vesuvianite veins.

VESUVIANITE VEINS

The veins containing the vesuvianite and associated minerals are

¹ See Folio 3 of the Geologic Atlas of the United States.

scattered over an area of several hundred acres. Most of them are near the center of the serpentine belt on a small hill west of Traverse Creek which will be referred to as West Hill, but a few small veins also occur on the other side of the creek. The distance between the veins most remote from each other is a little over half a mile.

Ten claims have been staked on these deposits by Mr. W. L. Stifle, who lives on the property, and the veins are exposed in numerous pits and prospect holes. Two short tunnels have also been driven in the serpentine near the veins but as yet they have not exposed any material comparable to that in the pits. It is impossible to say how many of these veins occur in the serpentine since those that have not been prospected easily escape notice, but several score may be seen in the pits and holes and doubtless many more exist. They range in dimensions from mere lenses and kidneys a few inches across to the size of the vein in the main "gem" pit on West Hill. This vein is three feet or more thick and has been worked to a depth of 15 feet and for 50 feet on the strike. Most of the veins are extended parallel to the shear surfaces of the enclosing rock but it may be that some cut across these structures. A few small massive veins show a little slickensiding but most of the veins show no disturbance at all.

Vesuvianite is by far the most important mineral in these veins. Other minerals, in order of importance, are garnet (grossularite and hessonite) diopside, clinochlorite, prehnite, tremolite and opal. In no single vein were all of these minerals found together. Many of the veins are nearly monomineralic. The vein in the main "gem" pit consists almost wholly of vesuvianite with only a little grossularite or clinochlorite in a few patches and many of the smaller veins consist wholly of vesuvianite.

There are many varieties of vesuvianite represented in these deposits. Most commonly it is yellow green and granular to massive. Some is nearly white or colorless and at least one large vein at "Gem Point" beside the road a quarter of a mile northwest of the ford over Traverse Creek, consists wholly of this variety in long acicular crystals. The darker varieties are found only in patches, often lining vugs. Violet or purple crystals, some conspicuously zoned, are rare and were seen only in the southern end of the main "gem" pit and in another nearby pit. The violet crystals occur in juxtaposition with very pale to green crystals.

Dense vesuvianite resembling the variety californite in structure, but rather pale and mottled, forms several small veins on the left bank of Traverse Creek.

ASSOCIATED MINERALS

The colorless grossularite forms many small veins alone or with some chlorite and diopside. It is granular to massive and contains only small

vugs lined with clear perfect crystals. It also occurs in patches in some of the large vesuvianite veins. Hessonite (used to designate a honey colored garnet higher in density and refractive index than the grossularite and probably containing more ferric iron) occurs in several small veins alone or with chlorite, diopside or vesuvianite but not with grossularite. One such garnet, occurring with clinochlorite in a vein on West Hill has a density of 3.65 and an index greater than 1.79, probably indicating a content of 30 per cent or more of the andradite molecule.

Dense white diopside forms veins enclosing small aggregates of green vesuvianite or occurs on the selvages of vesuvianite veins. Lath-like crystals of pale diopside up to 7 mm. long occur in small veinlets with prehnite on West Hill and in vugs in vesuvianite. Large poikilitic crystals of clear diopside enclose purple and colorless vesuvianite in one vein and a few clear glassy crystals of diopside occur in openings in a veinlet of hessonite.

Very pale, in part silvery, chlorite occurs both in the enclosing serpentine and in many of the veins. It may form selvages, fill in irregular spaces or occur as implanted crystals in vugs in vesuvianite or as minute rosettes on grossularite. The chlorite in most cases is optically positive, with small optic angle and has an index, β , near 1.58 and may so be classified as clinochlorite. Only adjoining the diopside-prehnite vein on West Hill mentioned above was some chlorite collected the optical properties of which show it to be diabantite.

Prehnite was not found with the vesuvianite. It was identified only in the veinlet with diopside just referred to and with garnet remote from the main group of veins.

Tremolite was only identified at one place where it forms a dense white band together with some clinochlorite adjoining a small vein of vesuvianite.

Although only 7 or 8 minerals have been identified in these deposits more than double that number of combinations were observed. In several places it is apparent that diopside or clinochlorite crystallized after vesuvianite or grossularite, opal occurs as a coating on prehnite and it may be that garnet encrusts vesuvianite in a few spots in the larger veins, but it does not seem possible to set up any simple sequence for the formation of all the minerals.

VESUVIANITE

Good clear crystals in a variety of colors are found in the vugs of the vesuvianite veins. At the time of the writer's visits no large vugs were exposed but they are said to have reached a diameter of about one foot. Most of the good crystals have come from the main "gem" pit in which scores of large crystal-lined pockets were found.

TABLE 1. SUMMARY OF PRINCIPAL FORMS FOUND ON VESUVIANITE FROM GEORGETOWN

Group of Crystals	Number of Crystals	Color	Ridgway Number	(001)	(110)	(100)	(120)	(111)	(331)	(221)	(112)	(011)	(021)	(031)	(045)	(131)	(132)	(263)	(151)
1	1	Pink, very pale	paler than 5."OO-R.f	1.00	1.00	1.00	0.37	1.00	0.25							0.75	0.62		
2	3	Very pale, dull green	paler than 27.'G-Y.f	0.66	1.00	1.00	0.46	1.00	0.67							0.96	0.54	0.33	
3	11	yellow																	
		Small light dull green	27.'G-Y.d	1.00	1.00	1.00	0.31	1.00	0.59	0.20		0.25	0.09	0.09		0.94	0.45	0.23	0.04
4	4	yellow																	
		Large clear dull green	27.'G-Y.b	1.00	1.00	1.00	0.69	1.00			0.50	0.62				0.56	0.34	0.12	0.09
5	5	yellow																	
		Small "Rivage" green	31.'Y-G.b	1.00	1.00	1.00	0.25	1.00	0.80	0.10		0.55		0.15	0.15	0.92	0.60		0.05
6	2	Large "Oriental" green	31.'GY-G	1.00	1.00	1.00	0.87	1.00				0.62				1.00			
7	5 (one doubly terminated)	green																	
		Small "Turtle" green	31.'Y-G.b	1.00	1.00	1.00	0.70	1.00		0.10	0.67		0.08			0.79	0.40	0.02	
8	4	Light grayish blue-violet	51.'BV-B.d	1.00	1.00	1.00	0.22	1.00	0.31	0.06				0.94	0.50				
9	3 (one doubly terminated)	"Rivage" green	31.'Y-G.b	0.25	1.00	1.00										1.00	1.00		0.72
All Crystals				0.90	1.00	1.00	0.36	1.00	0.47	0.13	0.06	0.33	0.03	0.06	0.03	0.85	0.50	0.10	0.10

HABIT. Thirty eight vesuvianite crystals, two of which were doubly terminated, were measured on the two-circle goniometer. It was found possible to arrange these crystals in nine groups based on color, habit and size. A summary of the results is given in table 1. In this table the persistence of each of the certainly identifiable forms is given for crystals in each group and for all of the crystals measured. The persistence of a form may be defined as the ratio of the number of times its faces were recorded in a certain group of measurements to the number of times they would have been recorded if the form were fully developed on all of the crystals in the group.²

The crystals of groups 1 to 8 are all from the main "gem" pit and it will be seen that some of them show nearly the same habit. All of the crystals show the forms (100), (110) and (111) completely developed and are prismatic in habit. The basal plane is present on nearly all crystals but is more conspicuous in groups 4, 6 and 7. In group 7 it is the dominant terminal face. The table shows that the occurrence of (011) is limited largely to these groups.

The crystals of groups 1, 2, 3 and 5 vary in thickness from 1 to 2.5 mm. and in length from 2 to 7 mm. The crystals of 4 and 6 are 3 to 6 mm. thick. The blue-violet crystals of group 8 are not over 1.3×4 mm.

The crystals of group 9 are from "Gem Point." Their color is quite similar to that of some of the others, but most of the less well crystallized material at this point is practically colorless. These crystals are thin and acicular, being a millimeter or less in thickness and having a ratio of length to breadth of 6 or more. They are notable for the perfection of the forms (331), (131) and (132) of which not a single face is missing in four terminations, the prominence of (151), and the almost complete suppression of the basal plane.

The habits of three of these groups are shown in figure 1, which gives a fair idea of the variation that may be found. All of the crystals are shown enlarged about twenty times.

MORPHOLOGICAL ACCESSORIES.—The table gives statistics only for the occurrence of the more persistent forms. Besides those listed, 17 other forms, including 12 not given in Goldschmidt's Atlas, which gave persistence values of 0.04 or less, were found.

Among the forms listed (045) is not given in Goldschmidt's Atlas. Included in the table under the indices (263) are narrow vicinal strips in the zone $[3\bar{1}0]$ between (131) and (132).

The form entered as (112) in group 4 occurs fully developed on two of

² Parker R. L., *Die Kristallmorphologie im Lichte neuerer analytischer Untersuchungen: Fortschritte der Min. etc.*, vol. 14, pp. 75-142, 1930.

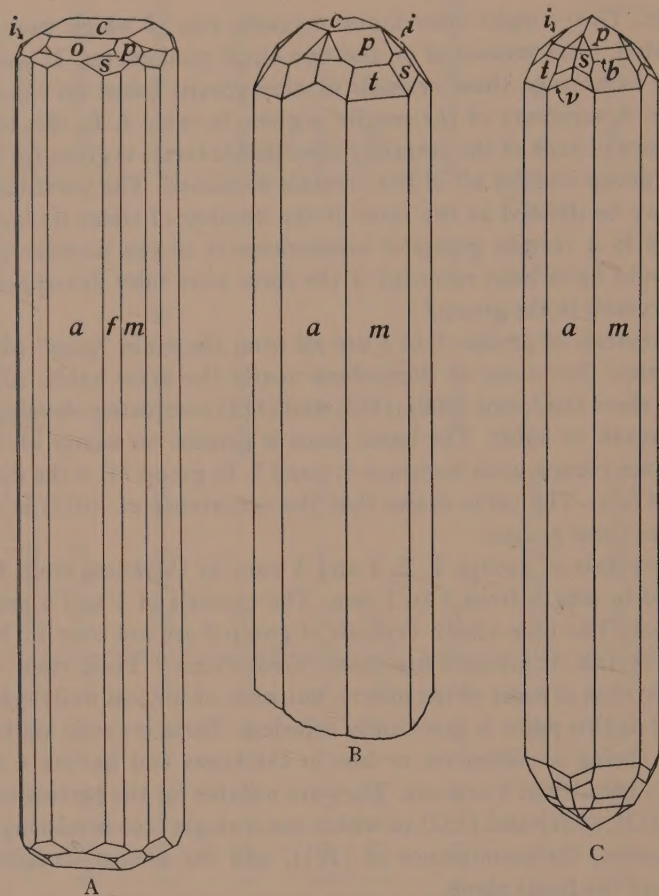


FIG. 1

<i>c</i> (001),	<i>o</i> (101),	<i>s</i> (131),
<i>a</i> (100),	<i>p</i> (111),	<i>i</i> (132),
<i>m</i> (110),	<i>t</i> (331),	<i>v</i> (151).
<i>f</i> (120),	<i>b</i> (221),	

A, Green vesuvianite, type 7,

B, Blue-violet vesuvianite, type 8,

C, Green vesuvianite, type 9.

the four crystals of this group. The faces are large but dull with only a bright fringe. The mean value of ρ for these faces is $19^{\circ}6'$, which is much closer to $18^{\circ}40'$, the value for (449), another new form, than to $20^{\circ}49'$, the value for (112).

Many of the crystals having prominent basal pinacoids show a rectangular pattern of striations on these faces. They are mainly in the

direction [010], but [110] striations or both were also seen on a few crystals.

Crystals in all the groups show a few light striations in the directions [011] and $[0\bar{1}1]$ on the faces of the second order prism.

The first order prism shows vertical striations on most crystals and in group 7 is replaced by a series of vicinal faces. In contrast to this the blue-violet crystals of group 8 show no vicinal faces at all in the prism zone and pronounced horizontal striations on the first order prism. The table shows that this group has the greatest development of *hhl* forms and wholly lacks *h0l* forms.

AXIAL RATIO.—Three groups of crystals showing the most conspicuous color differences were selected for the determination of the axial ratios. The results are shown in table 2. The differences are entirely within the limits of error and the value obtained is the same as that given in Goldschmidt's Winkeltabellen.

TABLE 2

Group of Crystals	Number of Observations	(111 \wedge 001)	Range	Axial Ratio
2	10	37°14 $\frac{3}{4}$ ' (111 \wedge 111)	37°13' — 37°17'	0.5376
8	4	74°30 $\frac{1}{4}$ '	74°27' — 74°36'	0.5377
9	4	74°29 $\frac{1}{4}$ '	74°28 $\frac{1}{2}$ ' — 74°30 $\frac{1}{2}$ '	0.5375

COLOR.—The wide color variations of the vesuvianite, even among crystals grown in juxtaposition lends some interest to the determination of the cause of these differences. Dr. T. G. Kennard of Claremont, California, made spectroscopic tests of a number of vesuvianites four of which are reported in table 3.

TABLE 3

Sample 1	Sample 2	Sample 3	Sample 4
Large:	Large:	Large:	Large:
Ca	Ca	Ca	Ca
Al	Al	Al	Al
Si	Si	Si	Si
Medium:	Medium:	Medium:	Medium:
Fe	Fe	Fe	Fe
Mg	Mg	Mg	Mg
	Small:		
	Cr		
Trace:	Trace:	Trace:	Trace:
Mn*	Mn	Mn	Mn
Ti	Ti	Ti	Ti
	Ni		

* The Mn content in sample 1 is considerably larger than in the other three samples.

Minute Trace:	Minute Trace:	Minute Trace:	Minute Trace:
Na	Na	Na	Na
B	B	B	B
V	V	V	V

Sample 1, Blue-violet crystals of group 8,

Sample 2, Turtle green crystals of group 7.

Sample 3, Pale green-yellow crystals of group 2.

Sample 4, Very pale crystals from "Gem Point" not included in table 1.

The results obtained are, of course, only qualitative but Dr. Kennard states that "trace" indicates the presence of hundredths of a per cent. The first three samples are all from the main "gem" pit. The last is from another pit several hundred yards north thereof and was chosen because the crystals were especially pale colored.

It will be seen that the minor constituents are nearly the same in all of the crystals and include several elements not found in the quantitative analysis (table 4). The blue-violet color of the crystals of group 8 appears to be caused by a slightly higher manganese content and the green color of crystals in group 7 seems to be due to chromium.

COMPOSITION AND FORMULA.—After preliminary spectroscopic tests by Dr. T. G. Kennard analyses of two specimens of vesuvianite were made by W. H. Herdsman with the results shown in Table 4.

TABLE 4. ANALYSES OF VESUVIANITE

	Green crystals	White vein material	$\text{Ca}_{10}\text{Al}_4(\text{Mg, Fe})_2\text{-(OH)}_4\text{Si}_9\text{O}_{34}$
SiO_2	36.60	37.70	36.96
Al_2O_3	19.75	19.30	13.94
Fe_2O_3	0.80	0.85	
TiO_2	trace	trace	
FeO	1.64	0.37	0.73
MgO	2.58	2.45	5.10
MnO	nil	nil	
CaO	37.80	38.30	38.34
$\text{H}_2\text{O}-$	0.20	0.10	
$\text{H}_2\text{O}+$	0.40	0.70	4.93
F	nil	nil	
CO_2	nil	nil	
Ni	nil	nil	
Cr_2O_3	0.18	nil	
	99.95	99.77	
S.G. $\frac{25^\circ}{4^\circ}$	3.326	3.322	

In the last column of the table is given the composition of an ideal vesuvianite having the formula of Warren and Modell and an Fe''/Mg

ratio of 0.08, about the same as that of the white vesuvianite. Both of the analyses show a very high Al_2O_3 content, higher than in any modern analyses of fluorine free vesuvianite quoted by Doelter. The sum of Fe'' and Mg is too low. This might be adjusted by assuming that a part of the Al is in positions equivalent to Mg and Fe'' , but no amount of juggling will raise the water content to correspond to that required by the formula.

OPTICAL PROPERTIES.—The indices of refraction of vesuvianite crystals belonging to three different color groups were determined for three wave lengths by the least deviation method on natural 45° prisms. A small Leitz monochromator, calibrated with Li, Na and Tl flames, was used.

TABLE 5. REFRACTIVE INDICES OF VESUVIANITE

	λ	$.589\mu$	$.535\mu$	$.480\mu$
Group 2	ϵ	1.707	1.711	1.717
Very pale	ω	1.710	1.714	1.720
Group 8	ϵ	1.708	1.712	1.718
Blue-violet	ω	1.710	1.714	1.720
Group 9	ϵ	1.7103	1.7140	1.7208
Green	ω	1.7129	1.7163	1.7224

The absorption of all varieties of the vesuvianite is so slight that no pleochroism is observable in thin sections or crushed grains, but by examining whole crystals in polarized light differential absorption can be seen in all but the palest. In groups 3 and 4 the absorption of the extraordinary ray is greater. In all the other groups the ordinary ray is more absorbed.

GROSSULARITE

HABIT.—Five colorless grossularite crystals from the main "gem" pit were chosen for measurement. All showed the forms (110), (211), (321) and (332). Three also showed very small cube faces. The habit of these and the other white garnets may be trapezohedral or dodecahedral and both types may occur in the same vein.

These garnets do not, in general, exceed 2 or 3 millimeters in maximum dimension. Only in one vein, consisting of garnet with minute rosettes of chlorite, were there found trapezohedrons of grossularite reaching 5 millimeters or more in diameter.

No measurements were made on other types of garnet.

COMPOSITION.—A chemical analysis of the grossularite made by Mr. Herdsman, following spectroscopic tests by Dr. Kennard, yielded the results in table 6.

TABLE 6. ANALYSIS OF GROSSULARITE

	Wt. %	mol. prop.	
SiO ₂	39.30	0.6544	0.6544
TiO ₂	nil		
Al ₂ O ₃	21.93	0.2151	0.2210
Fe ₂ O ₃	0.80	0.0050	
Cr ₂ O ₃	0.13	0.0009	
FeO	0.23	0.0039	
MnO	nil		0.6655
MgO	traces		
CaO	37.10	0.6616	
H ₂ O ₋	nil		
H ₂ O ₊	0.30		
CO ₂	nil		
Ni	nil		
	99.84		
S.G. $\frac{25^\circ}{4^\circ}$	3.5062	RO:R ₂ O ₃ :SiO ₂ =3.051:1.013:3.000	

OPTICAL PROPERTIES.—The refractive indices of the grossularite were determined by the least deviation method using natural 60° prisms and a small Leitz monochromator. The results given below are the mean of six determinations.

λ	.589 μ	.535 μ	.460 μ
n	1.737	1.741	1.748

AN X-RAY POWDER CAMERA

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The writer has used a battery of x -ray powder cameras of novel design for several years in conjunction with a Hadding gas tube. The cameras have given such satisfactory operation in this and several other laboratories that it seems desirable to publish a brief note of the design, which departs considerably from that of the usual powder camera, and offers a number of conveniences.

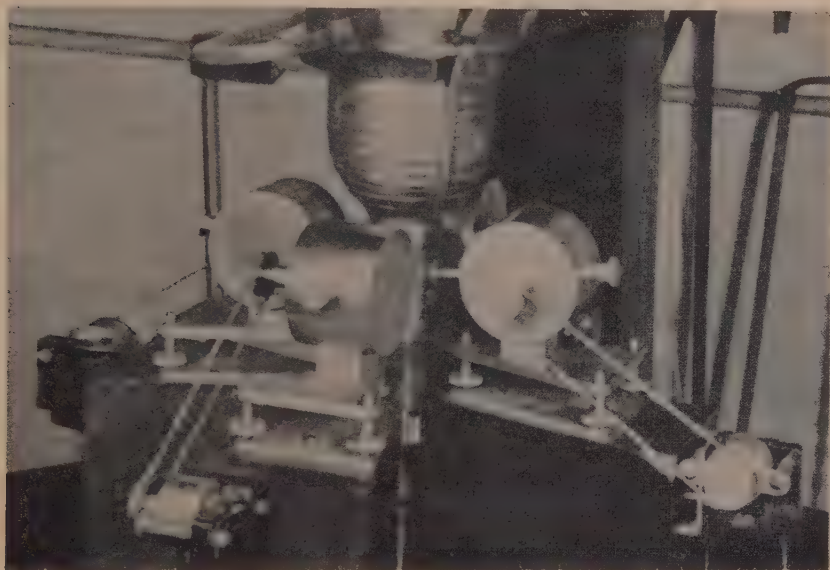


FIG. 1. Hadding x -ray tube with battery of four powder cameras. The support for each camera assembly is a wooden wedge which rests against cleats set at the wedge angle on the table top. Other apparatus may be used in conjunction with the x -ray tube by removing the wedges whose positions may later be exactly recovered by pushing them against the cleats.

GENERAL DESIGN.—The general appearance of the camera is indicated in figure 1 and the construction is illustrated in some detail in figure 2. The bare film is wrapped around the inside of the cylinder and held in place by two wedge rings, the inside one being soldered in place, the outside one loose. The film is protected from light by a screw-on cover.

The powder specimen, mounted as described beyond and attached to a $3/32$ inch brass rod, is held in a rotating, centering holder, illustrated in the lower part of figure 3 and described beyond. The inside of the

camera, against which the film is wrapped, and the bearing for the specimen holder spindle are turned and bored with the same lathe setting from a solid bronze casting, so there can be no eccentricity of the specimen as in most powder cameras.

The pin-hole system, illustrated in detail in the upper half of figure 3 and described further beyond, is arranged so that the pin-hole which

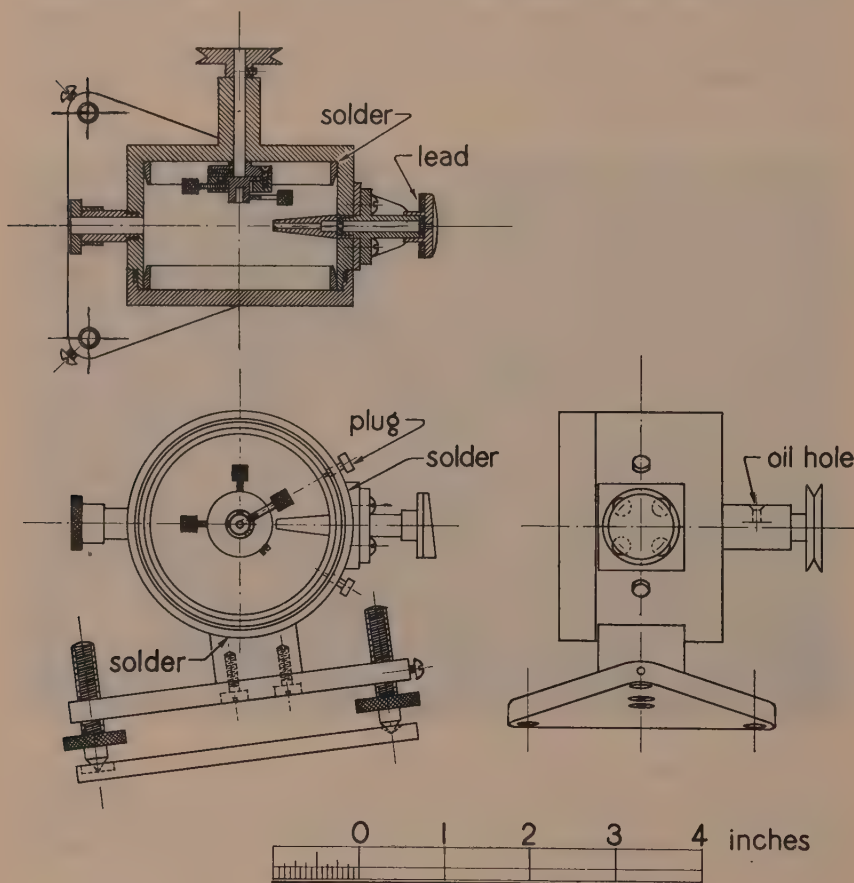


FIG. 2. Construction of powder camera. Levelling screws and lower base have been omitted from front view for clearness.

limits the rays is at the circumference of the camera to satisfy focussing requirements. The direct beam leaves the camera through a tube at the rear. In order to facilitate adjusting the pin-hole system to the best part of the x -ray beam, this exit port is fitted with a disk of fluorescent screen, held against the back of the tube by a friction cap. Patterson type B

fluorescent screen, facing outward and covered with cellophane for dust protection, has been found excellent for this purpose. The screen is backed with a disk of black paper to prevent the entrance of light into the camera.

The cylindrical body of the camera, soldered to a brass block, is adjustable on a triangular base by means of two loose-fitting screws. The base is supported by means of three pointed levelling screws which rest in three indentations of a second permanent, triangular base. The forward indentation is a cone, the others are a wedge groove and a flat groove respectively, giving a point-slot-plane support, so that the position of the camera is recoverable after removal for loading.

The sample is rotated by a type B3, 1 R.P.M., Telechron motor driving through a pair of pulleys connected by a looped rubber-band belt. The motor has no metallic contact with the camera. This prevents possible burning out of the motor windings in case of any sparking from the tube during times of temporarily erratic operation such as the breaking-in period.

DIMENSIONS.—The powder cameras illustrated are used chiefly for the identification of crystal phases by comparison of a film of the unknown phase with one of the suspected phase. For this purpose as well as many others, cameras of large diameter are not necessary. Indeed it is desirable to use cameras of as small a diameter as possible to cut down time of exposure. A convenient camera diameter is 57.26 mm., which makes one millimeter on the film correspond to a camera arc of 2° and to a glancing angle, θ , of 1° . The illustrations are for cameras of this size, but of course, the general design may be applied to cameras of any size. Films for this camera are $6\frac{3}{4} \times 1$ inches. They are conveniently prepared by cutting a standard 5×7 inch x-ray film into five 1 inch strips with the aid of a print trimmer and then finishing the strips as described beyond under *Film Size Uniformity*.

For the camera illustrated, the film ordinarily becomes over-exposed with unfiltered radiation if the exposure time exceeds 4 hours, using a sharply focussed Hadding tube running on half wave rectification, and passing 10 milliamperes at about 45 kilovolts. Shorter exposures are more usual, and considerable reductions may be made by using full wave rectification, and, at the expense of fine lines, by increasing the size of the limiting pin-hole in the pin-hole system.

MATERIAL.—The cylindrical body of the camera together with the spindle bearing are turned out of a single bronze, cup-shaped casting. The rest of the camera parts are made of brass, except as follows: The spindle, levelling screws and other large screws are of steel; the pin-hole system diaphragms and front cap backing are of 1/16 inch sheet

lead. All parts except the interior of the cylinder, and the adjusting sample holder, are nickel plated.

DETAILS OF CONSTRUCTION.—A detailed illustration of the centering specimen holder is given in the lower half of figure 3. The brass rod to which the sample is attached is held in the holder by means of the set screw operated by the outer knurled knob. The two inner knurled knobs operate two screws which translate the holder along two component directions at right angles to one another. The holder is held against these

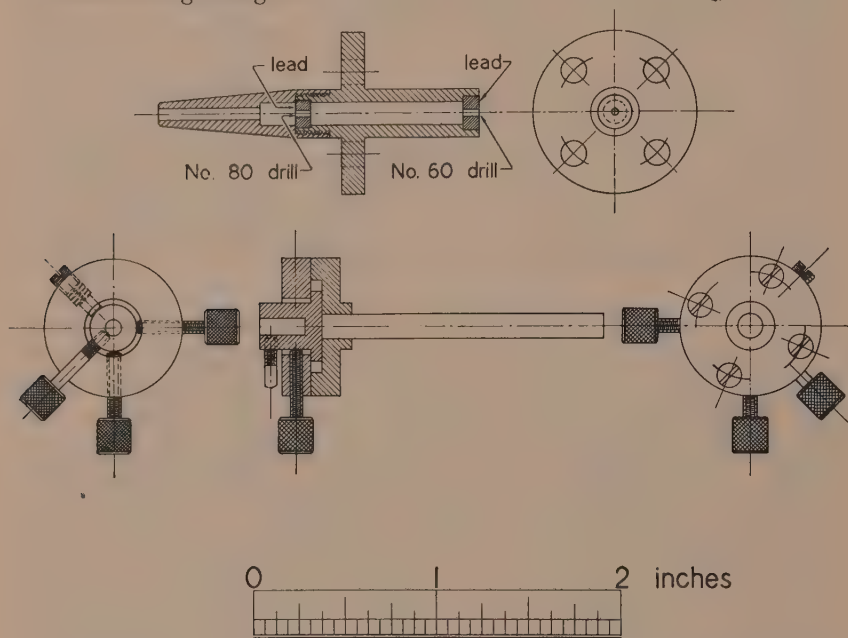


FIG. 3. Details of construction of pinhole system (above), and of centering specimen holder (below).

adjusting screws by a spring-actuated plug. This centering device enables one to make the axis of the powder sample accurately coincident with the axis of rotation.

The pin-hole system is illustrated in detail in the upper half of figure 2. It consists of two turnings which screw together. The right member bears the pin-hole system proper, consisting of two perforated sheet lead disk plugs. The 80-drill hole in the inner disk limits the beam and fits into a position at the circumference of the camera. The 60-drill hole in the outer disk merely limits the cone so as to prevent the x-ray beam from touching the sides of the exit port. This arrangement gives fine lines and excellent doublet resolution. The rays scattered by the inner pin-

hole are prevented from entering the camera by the conical cap which screws on to the pin-hole tube. The entire assembly is held by four screws to a block soldered to the outside of the camera cylinder. The holes in the pin-hole assembly, through which these screws pass, are purposely loose so as to allow a translation adjustment for making the pin-hole system axis intersect the specimen rotation axis. (See beyond, under *Primary Adjustments*.)

The cap on the end of the pin-hole system, illustrated in figure 2, serves three purposes: Its primary function is to make the camera light tight by holding a disk of black paper against the front pin-hole. When desirable, a piece of filter may be similarly held in the same place. In addition, the broad surface of the cap prevents accidental puncturing of the x -ray tube window if the camera should be carelessly placed against the tube, and its lead backing screens the camera against the direct beam when hard radiation is used.

A pair of plugs cover two 80-drill holes in the cylindrical part of the camera. Removal of these for a moment in an artificially lighted room exposes the film beneath these two tiny openings, so that when the film is developed, two small calibration dots appear. Their distance apart is a measure of the film shrinkage and permits calibration of the camera.

PRIMARY ADJUSTMENTS.—Before using the camera, the pin-hole system should be adjusted as follows:

1. A short section of 3/32 inch rod, having one end turned down to a thin needle, is clamped in the specimen holder. The caps are removed from the pin-hole system and exit port, allowing one to sight through the pin-hole system. When the spindle is rotated, the needle appears to execute a small oscillation as seen through the pin-hole system, because its axis is not in the axis of rotation. The two translation screws are adjusted until, on rotating the spindle, the needle remains fixed.

2. With the needle axis coincident with the spindle axis as described above, the four screws holding the pin-hole system to the camera are loosened. While looking at a well illuminated white surface through the pin-hole system it is translated up or down until the needle appears in the center of the field. The screws are then permanently tightened and the axis of the pin-hole system remains intersecting the axis of the sample rotation.

PREPARATION OF POWDER MOUNT.—The powder mount is easily and quickly made as follows (figure 4): a quarter inch length of 3/32 inch brass rod, held in pliers, is heated in a flame and a small lump of picein wax melted on to the tip of one end. A 5/16 inch section of fine glass capillary, made by drawing out pyrex tubing, is inserted into this wax after the latter is softened by reheating. After a short cooling period, the

axis of the glass capillary can be made accurately parallel to the axis of the brass pin by pressing the thumb nail into the piscein on the side toward which the capillary leans. Only the parallelism of axes need be adjusted by this means for the centering adjustment of the holder takes care of making the axis of the capillary coincide with the rotation axis. The mount for holding the powder is now complete. It is convenient to make up a large number of these at once, ready for application of any powder which it becomes desirable to mount.

After trying a number of procedures for mounting the powder, the following was found to be most convenient and give best results: The substance to be examined is ground in an agate mortar and heaped in a small pile at the edge of a small sheet of paper. A drop of mucilage from a Le Page's "grip spreader" is then placed on the edge of the thumb nail of the left hand, the mount is picked up in the right hand and the capillary rolled around in the mucilage to spread it evenly over the surface

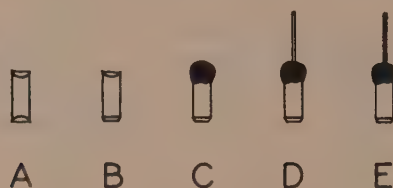


FIG. 4. Stages in preparation of powder mount. A. Rough $5/16$ inch section of $\frac{1}{8}$ inch brass pin as clipped from stock. B. Brass pin with lower clipping burr removed by filing. C. Brass pin with piscein lump melted on burr end. D. Pyrex glass capillary inserted in piscein. E. Completed mount with specimen powder stuck to capillary.

of the glass; then after picking up with the left hand the paper with the powder, the capillary is rolled around in the powder until an even coating adheres to it. Both the bare capillary mounts and the completed powder mounts may be stored by plugging the brass rods into holes in a wooden block in the same manner that machine drills are stored. The holes in the block should be shallow enough so that the brass part of the mount may be gripped in forceps for mounting and other handling.

LOADING.—The brass pin of the powder mount is clamped in the specimen holder by tightening the set screw knob, and the camera is set on a table with both the pin-hole system cap and exit port cap removed. The powder sample is transferred to the specimen holder of the camera by means of forceps, and the capillary centered in exactly the same way as the needle during the adjustment of the pin-hole system. The caps are replaced and the camera taken into the darkroom for loading. With the screw cover and outer film ring removed, the film is fitted against the inside of the cylinder and slipped down behind the permanent back ring, taking care that the edge of the film is not turned over

in wedging it home. The outer film ring is then wedged over the outside of the film, using the same precautions against deforming the film. The cover is then screwed on and the camera is ready for use. Note that the screw cover is fitted with threads for only half of its overlap with the camera cylinder. This arrangement permits seating the screw before tightening it and makes it virtually impossible to start the two parts of the screw in disregistry, a great convenience in the dark.

FILM SIZE UNIFORMITY.—Maximum information may be obtained from a film if reflections of both lowest and highest glancing angles are recorded. This camera is designed to accommodate a film which records

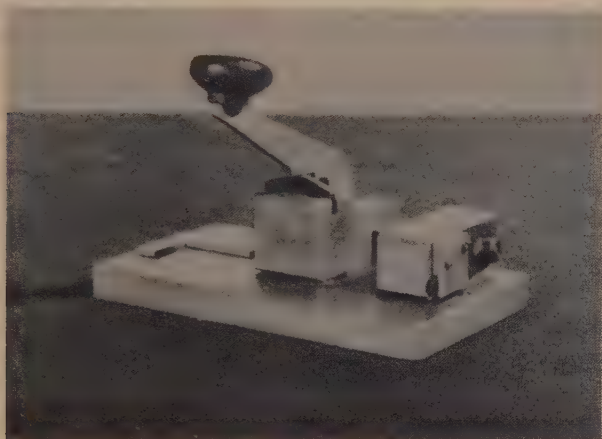


FIG. 5. Film trimmer for x-ray powder camera. The film is laid on the flat surface and pushed back and left against the cleats. When the knob is depressed, a central hole is punched in the film by a die in the central block and at the same time the right edge is trimmed to size by the knife.

reflections of high glancing angles limited only by the pin-hole system cone. In order to utilize the low glancing angle region most effectively, the hole in the film over the exit port of the camera should be clean-cut, accurately located, and of minimum dimensions. This is best taken care of by a punching and trimming outfit of the kind illustrated in figure 5. This takes a one inch film strip, cuts it to exact length ($6\frac{3}{4}$ inches) and at the same time punches a minimum size hole ($\frac{1}{4}$ inch) in the exact center of the film. In placing the film in the camera, the hole is automatically centered over the exit port because the free ends of the film just touch the pin-hole system cone.

ACKNOWLEDGMENT.—The writer is indebted to Professor J. T. Norton for a number of ideas used in the design of this camera. A comparatively crude prototype of similar proportions in use in his laboratory was used as a starting point in the design described.

SILICA-FLUORITE PSEUDOMORPHS

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ABSTRACT

An occurrence of silica-fluorite pseudomorphs, closely related to intrusions of basalt, has been observed in Los Angeles County, California. The prevalent form is a simple cube, with an occasional modifying tetrahexahedron (210). A rather odd form of built-up or "platy" cubes, was observed at one locality.

The material of the pseudomorphs is in great part finely fibrous silica, either "feathery," or intricately interlocking aggregates of fibrous grains. In part the silica is in the form of normal quartz grains, which may be more or less replaced by later fibers. A distinct zonal arrangement is not uncommon. Optical and x-ray evidence leads to the conclusion that the apparently different fibrous forms of silica are due to variant orientations of microcrystalline quartz.

Formation of the pseudomorphs is due to replacement from the outside, the exact character of the resultant silica depending on the precise conditions of temperature and concentration at the time of deposition. Warmer solutions are supposed to be responsible for the formation of quartz grains rather than of chalcedony, and continued deposition of silica, with falling temperatures, has allowed replacement of earlier formed quartz grains by chalcedony.

INTRODUCTION

Recently the writer has had the privilege of investigating an occurrence of pseudomorphs of quartz and chalcedony after fluorite. These have not been hitherto reported from California, and the occurrence presents some interesting and unusual features.

A search through geologic literature brings to light a moderate number of examples of the pseudomorphic replacement of fluorite by quartz or chalcedony. Some seventeen localities for this combination have been noted, a few of which, however, are described as incrustations, and which perhaps should not properly be classified as pseudomorphs.¹

¹ Haidinger W., Der rothe "Glaskopf," eine Pseudomorphose nach braunen, nebst bemerkungen über das Vorkommen der wichtigsten Eisenhaltigen Mineral-Spezies in der Natur: Abstr. in *Neues Jahrb. Min.*, **1847**, p. 66 [Johann-Georgenstadt, Saxony].

Sillem A., Ueber Pseudomorphosen: *Neues Jahrb. Min.*, **1851**, p. 385 [Zinnwald, Bohemia].

Sillem A., Berichte über eine Sammlung von Pseudomorphosen: *Neues Jahrb. Min.*, **1852**, p. 513. [Brioude, Haute Loire; Cornwall; Tresztya, Transylvania; Schneeberg, Saxony; Schwartzenberg, Thuringia].

La Croix A., *Mineraux de France et ses colonies*, vol. II, p. 779, p. 783. [Arouze and la Tourette, Haute Loire; Arne, Normandy; Morhiban, Brittany; various points in Loire Inferieure, Nièvre, and Saône et Loire].

Miers H. A., Some British Pseudomorphs: Abstr. in *Zeit. Krist.*, vol. **31**, 1899, p. 192 [Cornwall].

Miers H. A., and Bowman H. L., *Mineralogy*, New York, **1929**, p. 433 [Tresztya].

Credner, Pseudomorphosen von Quarz nach Flussspat, von Bischofsrode, bei Schleusingen: *Neues Jahrb. Min.*, **1859**, p. 799.

GENERAL GEOLOGY

The principal occurrence of the pseudomorphs is near the town of Encino, on the north slope of the Santa Monica Mountains, in Los Angeles County, California. A second locality is about four miles to the eastward, near the head of Higgins Canyon, and likewise on the northern margin of the mountains. The geology of the region in general has been mapped by Hoots,² who has shown this to be an area of Miocene sedimentary rocks, dipping to the north, and intruded by basalt. Detailed mapping shows that locally there has been developed a secondary dome-like structure on this northward-dipping series. The sediments are mainly thick-bedded, coarse arkosic sandstone, with a little intercalated shale, and occasional lenses of limestone carrying *Pecten peckhami*. This fossil, and the general correlation with surrounding territory, indicates a general Middle Miocene age (Topanga or Modelo).

Intruded into the sandstone, and probably causing its doming, is a thick, laccolithic mass of basalt, which has a surface outcrop about one hundred by four hundred yards. A thin-section of the fresh rock shows that it is largely made up of minute laths of twinned feldspar (probably andesine), with a few irregular grains of olivine and a very subordinate amount of glassy groundmass. A sub-parallel arrangement of the larger feldspars indicates flowage of the magma after partial solidification. The basalt shows no evidence of primary quartz, though quartz-bearing basalts are known in the Santa Monica Mountains.

The basalt was very thoroughly shattered, perhaps during the cooling process, though no regular joint systems are observable, and in some places it is so weathered along the joints as to resemble a volcanic breccia. It has baked and reddened the sandstone, particularly along the upper (southern) edge, for a distance of at least twenty feet from the contact. This intrusion, and its associated fractures apparently ended vigorous diastrophism at this locality, for veins, filling the fractures, are not broken or disturbed by later movement. These veins, from their field relations, are clearly connected in origin with the basalt. In addition to the larger mass, there are several other sill-like intrusive bodies, some with diabasic texture. These are mostly badly weathered, and likewise show no indication of original quartz.

Jumbo K., Some Korean and Sakhalin Minerals: *Abstr. Neues Jahrb. Min.*, 1908, II, p. 334 [Sakhalin].

Redlich K. A., Mineralogische Mittheilungen: *Neues Jahrb. Min.*, 1899, II, p. 218. [Cinque Valle, South Tyrol].

Laubmann H., Ueber Pseudomorphosen von Quarz nach Kalkspat aus den Flusspatgangen am Wolsenberg in der Oberpfalz: *Centralbl. Min.*, 1913, p. 355.

² Hoots H. W., Geology of the Eastern part of the Santa Monica Mountains, Los Angeles County, California: *U. S. Geol. Surv., Prof. Paper* 165-C.

OCCURRENCE AND TYPES OF PSEUDOMORPHS

In the sandstone there are, as noted, numerous irregular fractures, most of which are now filled, or partially filled, with chalcedony or crystalline quartz, the latter forming drusy surfaces in the open spaces. It is in these veins that the pseudomorphs occur, usually at scattered points close to the contact of the intrusive, but in one important locality at a considerable distance from the nearest outcrop of the main body of the basalt, though close to the termination of one of the small diabase sills. At the Higgins Canyon locality there is no indication of igneous rock for at least one fifth of a mile from the point of discovery.

Locality "B"

At this place a rather pronounced zone of jointing cuts at a high angle across the bedding of the sandstone, which here dips some 10° to 15° to the north. The veins are developed in this fracture zone, and form a close network, or stockwork, of chalcedony and quartz, some of which is pseudomorphous after fluorite. A diligent search in this area and at all other occurrences has failed to reveal the least trace of the original fluorite, which has evidently been completely removed.

Where the pseudomorphs occur, they are relatively abundant in the fissures where filling has not been complete, and there has been space for the free development of crystal faces. Even where the fissures have been completely filled, the outlines or "ghosts" of crystals may often be observed in the solid chalcedony, and it is not improbable that the fluorite was really much more widespread than at first appears, and has been covered by the later chalcedony. These buried pseudomorphs may also be observed in some of the thin-sections (Fig. 3). The megascopic character of the replacement and the consequent degree of perfection of the resulting forms, has been quite variable. The variations occurring at Locality "B" may be grouped into the following types:

(a) Perfect crystal forms, frequently translucent, with shiny faces and sharp edges and corners (Fig. 1).

(b) Crystals with sharp edges and corners, but with dull, though smooth, faces.

(c) Similar to *b*, but with occasional rectangular or square, clear shiny areas, or small inset cubes of clear material. (Not a common type.)

(d) Crystals with slightly rounded edges, and very dull, or even white, enamel-like surfaces (Fig. 4).

(e) A series of forms with increasingly rounded edges, becoming more and more botryoidal, till the edges and corners are bounded by a series of part-globular surfaces, resembling a string of mutually interfering beads. The faces of such specimens are of course finely botryoidal also.

(f) Similar to type *e*, but coated over with a crust of minute quartz crystals. One specimen showed a single individual pseudomorph partly "sugared" with quartz and partly plain botryoidal (Figs. 2 and 3).

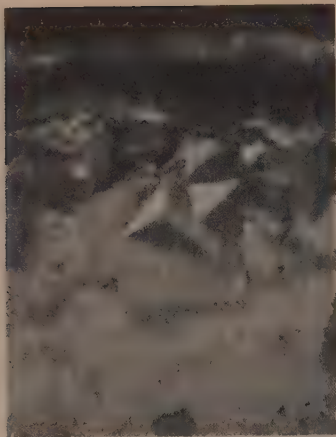
(g) The extreme type of modification, the forms showing more and more rounded edges, until by degrees the original forms are merely suggested on the surface, and finally are completely obliterated.

(h) Aggregates of type *a* or *b* crystals, built up into towerlike or rounded protuberances on a crystal covered surface. In these aggregates, there is no particular orientation of the individuals, which project out in all directions from the core of the group.

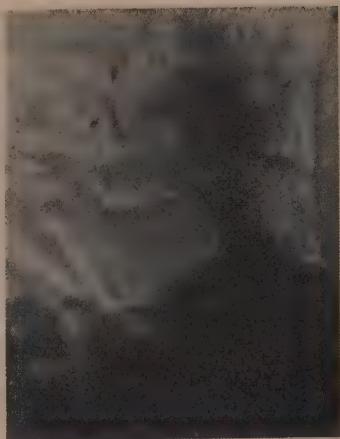
Any of these different types of pseudomorphs may occur as a drusy coating over the entire surface, or as more or less widely separated individuals. The type and mode of occurrence may vary, even within the limits of a single hand specimen, from closely packed to widely spaced crystals, or from clean-cut to botryoidal forms. Almost invariably the crystals are perched on a series of thin layers of chalcedony which coats the fissure walls, and in some instances are apparently embedded in this material. Several specimens show minute cubical cavities, iron-stained, or even filled with limonite, probably pseudomorphous after pyrite.

The largest crystals at this locality do not exceed one quarter inch on edge, and most of them are considerably smaller. They are usually simple cubes, with occasional interpenetration twins parallel to the octahedron, but a few individuals show a modifying tetrahexahedron (210). No other forms were observed, but these characteristics render reasonably certain the identification of the original material as fluorite. Some of the quartz crystals from adjacent cavities show a strongly rhombohedral habit, and since the rhombohedron is cuboid (the interfacial angle is $85^{\circ}46'$) these may be mistaken on casual inspection for pseudomorphs. The difference in form, shown by closer examination, and the true vitreous luster of these crystals, serves to distinguish them from the less brilliant pseudomorphs.

Thin-sections of the pseudomorphs from Locality "B" show in general, normal microscopic structures, well illustrated by the photomicrographs (Figs. 3, 4, 5). Zoning is pronounced in some specimens, and nearly absent in others. The constituent grains vary in size from 1 mm. to .005 mm. across, and betray their uniformly fibrous character by their ragged extinction under crossed nicols. Only two of the specimens from this locality showed any indication of originally larger grains replaced by aggregates. As will be seen, this is in marked contrast to structures from Locality "A." All specimens from Locality "B" if cut normal to the crust, show underlying layers of chalcedony with colloform texture, upon which the pseudomorphs themselves are seen to rest. The exterior coatings of chalcedony are definitely later than the chalcedony of the pseudomorphs themselves, and show the physical characteristics of the ordinary mineral. This is in distinct contrast with the underlying layers, and the pseudomorphs.



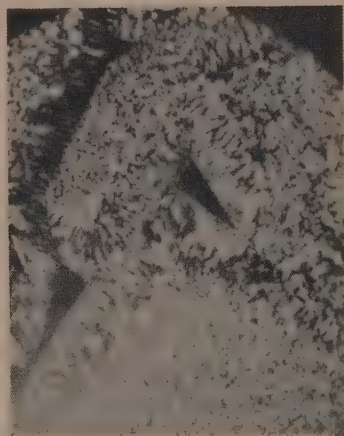
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4

FIG. 1. "B"×18. Typical specimen of type *a* crystals, with simple cubes scattered over a botryoidal surface. Shows twinning on (111).

FIG. 2. "B"×10. Cube crusted with botryoidal chalcedony and partly "sugared" with quartz.

FIG. 3. "B"×34. Same specimen as Fig. 2, thin section with crossed nicols. "Sugared" cubes. The outline of the cubes themselves is clear-cut, while the crust has rounded and softened the external outline. Note the variable size of grains in the replacing chalcedony, with a zonal tendency. In the lower portion of the figure, the border grains tend to be roughly normal to the surface. The chalcedony of the crust is typical long-fibered material, in cone-like bundles, and is capped by a thin layer of quartz crystals, which show crystal faces on their outer ends.

FIG. 4. "B"×34. Crossed nicols. Section of type *b* crystals, showing a thin coating of very fine-grained material on the surface, then a layer of "feathery" chalcedony, with the fibers arranged roughly normal to the surface. The interior shows almost exclusively fine-grained jasperoid chalcedony.

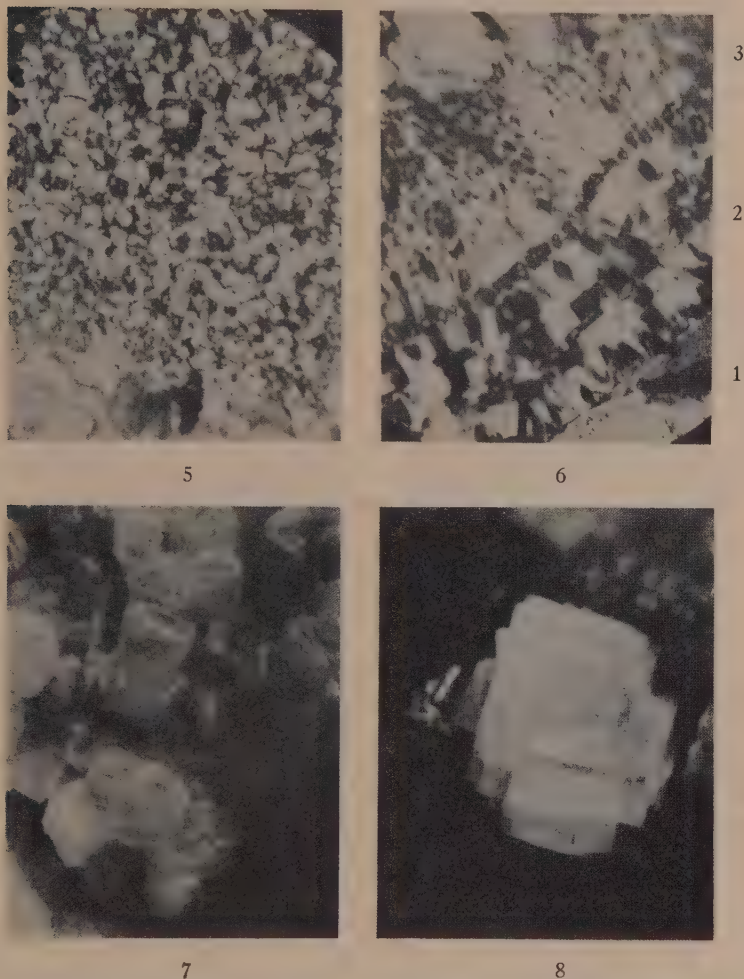


FIG. 5. "B" $\times 144$. Same specimen as Fig. 4, crossed nicols. Shows in detail the texture of the jasperoid silica. As may be seen, the grains interlock with each other most intimately, and by racking the microscope tube up or down, the apparent contact between grains migrates one way or another, showing that this texture is distinctly three-dimensional. The extinction of these grains is wavelike, travelling with the rotation of the stage, indicating a fibrous structure.

FIG. 6. "B" $\times 144$. Crossed nicols. Vertical section through a crust of α type crystals, showing the sandstone foundation (1), overlain by a series of layers of chalcedony (2), which shows a sharp contact with (1), and a less distinct contact with the overlying crystals (3), which were originally fluorite but are now altered to "feathery" and jasperoid chalcedony.

FIG. 7. "A" $\times 7$. Typical mode of occurrence of "platy" cubes on a botryoidal crust. Sometimes the crystals are so closely spaced as to cover the surface completely.

FIG. 8. "A" $\times 7$. A single individual of the "platy" type. Note the building out of the cube faces, and the tilting inward of some of the slabs. Photograph taken parallel to a cube axis.

Locality "A"

Here the pseudomorphs occur in the reddened sandstone close to the basalt contact, and show several decided differences from those at the other localities. The crystals are not ordinarily simple, though some cubes, and some twinned forms, were noted. Instead, they are typically in a unique form, which is basically cubic, but built up along the cubic axes so that the form, in profile, frequently approaches the aspect of a Maltese cross (Fig. 8). Built-up crystals are of course rather common in fluorite, but are apt to produce either octahedral forms with cube faces, or quite irregular aggregates of parallel growths, in contrast to these cruciform or "dished" crystals.

The crystals in this locality are practically all translucent or quite transparent, often with a distinctly bluish cast, and as most of them rest on a more or less reddened surface, the color effect is frequently almost purple. Most of them are superimposed on a thin, botryoidal crust of chalcedony or of red iron oxide. Many crystals are so transparent that the underlying crust can be seen directly through them, affording positive proof that they were formed earlier than this crust.

A thin-section of some of the "platy" crystals from this point showed a most unexpected result. Instead of showing a fine-grained aggregate of chalcedony particles, they were seen to be made up of relatively large individuals of ordinary quartz (Fig. 9). One point in the section, in fact, seems to show that a single quartz grain has replaced parts of two adjacent fluorite grains. More commonly a single fluorite crystal has been replaced by several quartz grains. In other thin-sections, the original presence of larger quartz grains is usually quite evident, but they are seen to have been replaced wholly or in part by "feathery" chalcedony. This replacement has proceeded from the borders of grains (Fig. 10), or along crevices (Fig. 11), in some cases leaving residual cores, and in others only the outline of the original grain (Fig. 12). As at Locality "B," every section cut vertically through the crust of crystals, shows them to be emplaced on a layer, or series of layers, of finely botryoidal chalcedony which has been deposited directly on the crevice walls.

Several specimens here, also, show a coating of later botryoidal chalcedony, under which the crystals may be partly or completely buried. This chalcedony, as usual, is definitely later than the crystals, and is distinctly different in type from the earlier material. Many of the crystals here are larger than those at "B," some reaching a size of $5/16$ ", though others may be much smaller. They occur covering the whole surface, or scattered over it, as in the other localities. No opaque or milky white crystals were observed at this point. The smaller, simple cubes are in general much more transparent than any of the others.



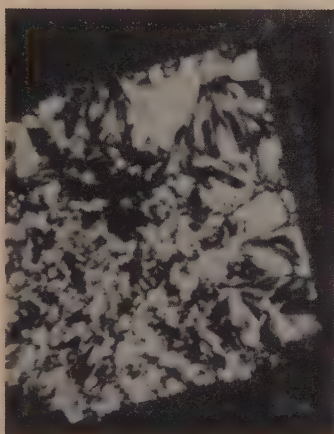
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FIG. 9. "A" $\times 34$. Crossed nicols. Section, nearly parallel to a cube face, through a crystal like that shown in Fig. 8. Shows complete replacement of fluorite by quartz grains of considerable size. In this and similar crystals in the section, there has been little or no secondary chalcedony developed in the outer part, but at their "roots" this replacement appears to have begun. The sections show that this secondary replacement is the general rule and that unaltered specimens are the exception.

FIG. 10. "A" $\times 144$. Crossed nicols. Another point in the same section as Fig. 9, showing in detail the secondary replacement of quartz by chalcedony. Note the clear-cut boundary between the original quartz and the new material, though the fibers do not all seem to reach it. This is due to their variable orientation, as rotation of the stage shows that the fibrous material in all cases extends up to this boundary, and that the apparently ragged contact is not real, but due to the peculiar extinction of the fibers.

FIG. 11. "D" $\times 144$. Crossed nicols. An illustration, from a different specimen, of the same process shown in Fig. 10, proceeding from a crack in the quartz, instead of from the periphery. Here also it can be seen that the true contact between old and new is a smooth surface. In addition this slide shows (lower right), "growth-lines" of the fluorite, retained in the quartz.

FIG. 12. "A" $\times 34$. Crossed nicols. This section is from a specimen on which occur both simple and "platy" cubes, coated by or completely buried under ordinary chalcedony. The figure shows one of the simple cubes, and is introduced to show complete secondary replacement of originally large quartz grains by "feathery" chalcedony. The borders of these grains are in many cases quite evident, but there was probably also some fine-grained chalcedony present in the original replacement of fluorite.

Locality "D"

Only one specimen was collected at this point, showing crystals of type *a*, but with the apparent luster of true quartz on the fresh fracture. This is apparently unique, as none of the other pseudomorphs shows this luster, but a thin section shows their true character. They are very perfect pseudomorphs, made up of large quartz grains, which in a few places have been partially replaced by later chalcedony (Fig. 11). The distance of this specimen from the igneous rock contact is unknown, since the outcrop is small, and bedrock is covered largely by a mantle of weathered material.

Locality "E"

One other unimportant locality, between "A" and "B," shows a few small pseudomorphs of the "A" type, and the sandstone has the same appearance as at "A," although no igneous rock is visible nearer than a hundred yards. It is likely that the contact is close beneath the surface at this point.

Locality "F"

This occurrence, near the head of Higgins Canyon, about four miles east of the main locality, shows a number of differences from the latter. The pseudomorphs are in a limestone breccia (or occasionally in shale), and the crusts of crystals are frequently broken up, disturbed in position, and re-cemented by fine-grained calcite. As a rule the crystals are almost microscopic in size, requiring the use of a hand lens for their sure determination. A few specimens, however, show crystal faces a quarter inch across, comparable to those elsewhere. The specimens usually occur in a very thin, drusy crust, which in some cases shows a crude parallelism of the individuals. Most of the crystals here are not simple cubes, but are parallel aggregates, sometimes suggesting the "platy" crystals seen at Locality "A." The distinct botryoidal underlying crusts of the other localities are conspicuously absent, though poorly indicated at a few points.

Thin-sections cut normal to the crust show usually a surface of calcite crystal terminations coated over by fine-grained chalcedony (frequently interlocking), on which, with a fairly sharp contact lies a zone of coarser "feathery" chalcedony, showing a distinctly parallel arrangement of elongated grains, exactly like the shingles on a roof.

As indicated in the hand specimens, none of the characteristic underlying layers were observed, though the transition from fine-grained to coarser chalcedony is quite similar to that in the other localities. The outermost part of the crust is made up of ordinary granular quartz, showing on the surface the outline of the fluorite cubes. The specimens

here show in general more preservation of fluorite "growth-lines," or crystal boundaries, than at "A," and one particularly good instance was noted of at least two fluorite individuals replaced by a single quartz grain. One section showed alternating layers of calcite and quartz beneath the pseudomorph crust.

In the case of the larger quartz grains, there is no good indication of replacement by a second generation of chalcedony, although in some of the grains are small inclusions of differently oriented quartz. These inclusions appear, with higher magnification, to be blebs or rodlike grains scattered haphazard through or between the larger quartz individuals. Some of these may be fibrous, though this is somewhat dubious.

FORMATION OF THE PSEUDOMORPHS

The process of formation of the pseudomorphs may have taken place somewhat as follows: Enveloping any crystal in an essentially stagnant solution, is a zone in that liquid, more or less narrow, of a saturated solution of the crystal substance.³ Unless the whole body of the solution is saturated, the concentration of this solution diminishes with increasing distance from the surface of the crystal. If now a new substance is brought near the crystal by diffusion (or other means), this saturated solution of the crystal may produce, close to its surface, a supersaturation of the new substance. If this happens, the new material, as it is brought in, will be precipitated practically on the surface of the old, which in turn will continue to be dissolved (perhaps at an increased rate, because of the presence of the new), removed by diffusion, and dissipated. The result will be, at first, the formation of an extremely thin layer of the new substance on the surface of the old, out through which the old may diffuse and in through which additional new material may work its way. Since this crust is newly deposited, it is probably relatively porous in texture, and hence readily pervious in this manner. Inside this crust, or shell, the solution will remain saturated for the old mineral, and hence able to cause precipitation of the new. Outside, however, since the crust was first deposited at the outer margin of the saturated zone, the solution will be more dilute, and unable to produce this result. Accordingly, new material will be added only on the inner surface of the crust. A continuation of this process under uniform conditions will result in the perfect preservation of the external form of the old crystal. The internal texture will depend on several factors, such as temperature, pressure, character of the solutions, state and concentration of the new substance, and rate of replacement. The varying modes

³ Noyes A. A., and Whitney W. R., Ueber die Auflösungsgeschwindigkeit von festen Stoffen in ihren eigenen Lösungen: *Zeit. physik. chem.*, vol. 22, p. 689, 1897.

of aggregation of the silica in these pseudomorphs reflect changes, perhaps quite minor, in local conditions at and following the time of precipitation.

FORM OF THE SILICA

There is general agreement that silica is largely transported as a colloid,⁴ and the suggestion has been made that it is deposited as a gel, and recrystallized, if at all, in successive stages, due to the rearrangement of constituent parts, and growth of larger grains at the expense of smaller.⁵

As may be seen from inspection of the photomicrographs, the silica of the pseudomorphs occurs in three physically distinct forms. These forms are: (1) ordinary quartz grains, of fair size, showing all the optical properties of the normal mineral (Fig. 9); (2) closely interlocking grains, very small, showing by their uneven extinction a fibrous structure. Occasionally a "eutectoid" texture is produced by a tendency towards parallel extinction of part of the grains over a limited area (Fig. 6); and (3) elongated fibers, or "feathery" silica, sometimes radiating or sub-parallel, or irregularly oriented (Fig. 12).

Optical observations on the interlocking material are unsatisfactory because of its almost sub-microscopic texture, but suggest characters similar to those of the "feathery" fibers. In the case of the latter, some of the properties were determined for the writer by Professor J. E. Wolff,* as follows:

the length of the fiber is in the negative direction, and consequently represents the lower index of refraction; assuming this as the vertical axis, this is the extraordinary ray and across the fibers the ordinary ray, the opposite of quartz. Of course if the vertical axis lies across the fiber this would be the ordinary ray like quartz, but there is no way of telling. I find for the ray vibrating parallel to the fibers, in eight determinations on separate pieces for sodium light, values varying from 1.5360 to 1.5460, the average being 1.5399. Across the fibers the index is slightly higher than parallel, but it is impossible to get an accurate reading. In general with this material there has been great difficulty in getting reliable refractive indices, due to the minute size of the fibers, their curving and overlapping. This also was noticed: the fibers sometimes, while still negative, exhibit a small obliquity of extinction to the length (like lutecite), and also have a higher relief than an isotropic substance filling minute interspaces parallel to the length,

[This isotropic substance is quite probably opal.] These properties cor-

⁴ Boydell H. C., The Role of Colloids in Ore Deposition: *Trans. Inst. Min. and Met.*, vol. 34, 1925, Part I, p. 145.

Lindgren W., in Bogue, *Theory and Application of Colloid Behavior*: vol. II, New York, 1924, p. 454.

Moore E. S., and Maynard J. E.: Solution, Transportation and Precipitation of Iron and Silica: *Econ. Geol.*, vol. 24, p. 390, 1929.

⁵ Boydell H. C., *Op. Cit.*

* Private communication

respond in general to those of chalcedony, and since the interlocking grains appear similar, though with less distinguishable structure, it is likely that they also are chalcedony.

According to a number of authors,⁶ there are three varieties of fine-grained silica, differing from quartz [chalcedony, quartzine and lutecite]. These authors are not in entire agreement about these, some considering them biaxial, and some uniaxial. Further, the indices of refraction, and specific gravities, as determined by Wetzel, are to be regarded with caution, in view of his recognition of the presence of opal admixed with the finely fibrous material. Others⁷ suggest that the observed differences are probably due to different orientations of the fibers, and to mechanically admixed opal. The writer has confirmed the findings of White and of Kerr with respect to *x*-ray structures, and has determined, by *x*-ray powder photographs,⁸ that the pattern is identical for quartz, ordinary chalcedony, and the "feathery" chalcedony of the pseudomorphs. Rogers,⁹ in writing of the different forms of silica, does not mention quartzine or lutecite, evidently considering them identical with chalcedony. Accordingly, we may probably consider the fibrous varieties of silica in the pseudomorphs mere variants of ordinary quartz, in fibrous form, and call them all chalcedony.

Outside of the pseudomorphs there are also three modes of occurrence of silica, namely, the normal, long-fibered, botryoidal chalcedony coating the crystals, the ordinary quartz crystals, and the thin botryoidal crusts on which the crystals rest. The last of these seems to correspond

⁶ Miers, H. A., and Bowman H. L., *Mineralogy*, New York, 1929, p. 433.

Lacroix A., *Min. de la France et ses Col.*, vol III, pp. 120, 131.

Wetzel W., *Untersuchungen über das Verhältnis von Chalcedon und Quarz zur Quarz: Centralbl. Min.*, p. 356, 1913.

Balogh E., *Die bituminösen Kalke und ihre Mineralien aus der Umgebung von Kolozvar, Kajanto und Torda: Abstr. in Neues Jahrb. Min.*, II, p. 40, 1914.

⁷ Dana E. S., and Ford W. E., *Textbook of Mineralogy* 4th Ed. New York, 1932, p. 472.

White W. P., *Quartz Inversion in Chalcedony: Abstr. in Bull. Geol. Soc. Am.*, vol. 35, p. 122, 1924.

Palache Charles, Private Communication.

Peacock M. A., *The Nature and Origin of the Amphibole Asbestos of South Africa: Am. Mineral.*, vol. 13, p. 241-286, 1928.

Kerr P. F., *Determination of Ore Minerals by X-Ray Diffraction Patterns: Econ. Geol.*, vol. 19, p. 30, 1924.

⁸ These *x*-ray pictures were kindly made for the writer by Professor O. L. Sponsler of the University of California at Los Angeles, to determine the atomic structure of the silica, since it had been suggested that possibly this silica might have occupied the lattice of the original fluorite. This was shown not to be the case, as the pseudomorph material gave identical patterns with ordinary quartz, and totally different from fluorite.

⁹ Rogers A. F., *Natural History of the Silica Minerals: Am. Mineral.*, vol. 13, p. 74, 1928.

closely to the "feathery" chalcedony in the pseudomorphs, but the first is physically quite different, though optically the same. In the underlying crusts the fibers frequently show patchy extinction, the shadow traveling along the length of the fiber with rotation of the microscope stage, indicating possibly a spiral or twisted structure. This curving, as noted above, was also observed in the "feathery" chalcedony of the pseudomorphs.

PARAGENESIS

Fluorite may occur under a wide range of conditions of temperature and pressure, even as the product of relatively cold waters in sedimentary rocks¹⁰, but in the vast majority of cases is closely connected with igneous rocks. The usual association for fluorite is with acid magmas, but in this instance the connection with the basalt is very close, and apparently constitutes a good example of an uncommon type.

The temperature of formation of the original fluorite veins was probably not very high, not over 360°C., judging by its close association with the early chalcedony. Experiments in the synthesis of quartz and chalcedony¹¹ indicate a probable upper limit for the formation of chalcedony at about 360°C., which would then be a maximum for this deposit. The fluorite solutions must have been fairly well heated, due to the presence of the igneous intrusion, so that this maximum temperature is likely to have been near the minimum also.

Deposition of fluorite in small crystals apparently exhausted the supply of this mineral, and its place was taken by silica, which was not present, or at least not being deposited, during the fluorite period. This silica, in the cooling but presumably still warm solutions, replaced the fluorite and formed the pseudomorphs. In the areas nearest to the igneous rock, where the solutions were warmer, the silica was deposited largely as quartz, while in the cooler places replacement was in the form of jasperoid or "feathery" silica.

At Locality "A," after the formation of the pseudomorphs, there was apparently a change in conditions, allowing the replacement of originally deposited quartz by later chalcedony. The latter is identical in appearance with that deposited earlier both here and in the other localities. This new generation of silica is clearly shown in the partial or complete replacement of the original large quartz grains.

After a distinct time interval, and under clearly different conditions,

¹⁰ Mügge O., Sandstein mit Flussspatzement: *Centralbl. Min.*, p. 33, 1908.

Fitzgerald P. E., and Thomas W. A., Occurrence of Fluorite in the Monroe Formation, Vernon Township Pool, Michigan. *Bull. Am. Assoc. Pet. Geol.*, vol. 16, p. 91, 1932.

¹¹ Koenigsberger J., und Muller W. J. Versuche über die Bildung von Quarz und Silicaten: *Centralbl. Min.*, pp. 339, 353, 1906.

the pseudomorphs were in many places coated over, or even completely buried by a crust of chalcedony, sometimes followed by later quartz. As noted above, this chalcedony is quite different in its microscopic appearance from the underlying crusts, and invariably rests on the pseudomorphs with a sharp contact, never blending even with the second generation chalcedony of the pseudomorphs.

While the crystals from some of the localities are normal cubes, or cube and tetrahexahedron, many, though not all, of those from "A" show the curious "platy" form already described. There is no microscopic evidence as to the original internal structure of these, so it is impossible to say, from what can now be seen, whether the original material was in simple individuals, or as crystal aggregates with an approximation to parallelism. This latter suggestion is possible, and might account for the odd forms here developed. No particular reason has occurred to the writer as to why such crystals or aggregates should have developed, except the presence of special conditions of material supply, or peculiar internal molecular stresses, or both. It is true that certain other specimens show a possible incipient development of this form, in the shape of jagged or "stepped" faces, notably at Locality "F," and in other cases there are knob-like aggregates of cubes (Locality "B"). These latter resemble the "platy" cubes only to a very limited extent, as the component crystals project in all directions from the clumps, without any semblance of orderly arrangement. Moreover, many of the "platy" cubes rest on a flat surface which can in some instances be actually seen through the crystals, and the knobs are usually built up from underlying knobs of chalcedony.

SUMMARY

The general sequence of events at Localities "A" to "E" appears to have been as follows:

1. Intrusion of basalt, with doming and fracturing of the sandstone cover.

2. Deposition of thin layers of chalcedony from heated solutions whose source was presumably the basalt.

3. Deposition of fluorite crystals, apparently unaccompanied by silica. The solutions were still hot, but under 360°C.

4. Replacement of fluorite by quartz or "feathery" chalcedony.

5. Replacement of some of this quartz by later "feathery" chalcedony.

6. Deposition, perhaps from rather cool solutions, of the overlying chalcedony crusts.

7. Finally, in a few places, deposition of tiny quartz crystals on all earlier crusts.

At Locality "F" the sequence is somewhat different.

1. Deposition of alternate layers of calcite and silica (quartz or chalcidony), by solutions from an assumed underlying igneous source.
2. Deposition of fluorite.
3. Replacement of fluorite by quartz and "feathery" chalcidony.

ACKNOWLEDGMENTS

The writer wishes to express his indebtedness to the following persons, who in various ways have aided in the preparation of this paper: a field party of geology students at the University of California at Los Angeles (Messrs. F. E. Bergeron, H. C. Bemis, and B. R. Ellison), who discovered the pseudomorph locality; Professor O. L. Sponsler of the University of California at Los Angeles; Professor J. E. Wolff and Professor Charles Palache of Harvard University.

A STUDY OF FELDSPAR TWINNING IN A DIFFERENTIATED SILL

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ABSTRACT

The observation has frequently been recorded that certain twinning laws (such as pericline) are more commonly encountered in basic rocks, while other laws are especially characteristic of acid rocks. As a follow-up on this observation and in a search for the causes that control twinning, a suite of thin sections taken from the bottom to the top of a differentiated sill was studied statistically to determine whether there are any variations in the nature of the twinning with change in composition of the rock. Over fourteen hundred twins were examined. They showed a statistical increase in the *number* of twins with increase in basicity, or anorthite content, of the sill. They indicated that there is no change in, or control of, the *type* of twinning law with the composition of the rock as it appears after crystallization. Another factor still unknown, and not composition must be responsible for the variation in twinning in different types of rocks.

INTRODUCTION

The determination of feldspar twinning laws, though regarded as an interesting study, has not yielded results of a practical nature, and therefore has not received sufficient attention by the American petrographers.¹ The more common twinning laws are well known by name, but are usually assumed rather than determined. The rarer laws are far too little known even by name. We have virtually no understanding of the relationships between twinning and rock type. The underlying factors which decide which twinning law shall prevail, are quite unknown. Feldspar twinning, at present, is little more than a useful criterion for the ready recognition of the mineral. It is incredible that a phenomenon so common as feldspar twinning can be so devoid of significance.

On the tentative assumption that the twinning laws present in a given rock might be a characteristic of that rock and serve as an earmark for purposes of correlation, a study was made of the twinning of

¹ As early as 1876 Rath (36) described twins of the Manebach and pericline laws, and his work was soon followed by similar descriptions by Mallard (26) in 1876, Michel-Lévy (31) in 1879, Glinka (16) in 1889, Viola (47) in 1900, and Melczar (30) in 1905. These early determinations were made by measuring angles on the goniometer. Real advance in the study came with Fedorov's invention of the universal stage method, described in 1901 (14). Nikitin (32), a pupil and collaborator of Fedorov, was one of the first to use this method. Duparc (11) introduced Fedorov's methods to the Laboratory of Mineralogy of the University of Geneva in 1912, having himself learned them directly from Fedorov and Nikitin. With the improvement in method the study of twinning proceeded rapidly, led by Nikitin, Duparc, and Reinhard, until now the study of twinning laws is an accepted part of the complete study of structure containing feldspars.

some of the granites of the Front Range.² This yielded no definite results, possibly because the thin sections represented widely scattered specimens from large areas. It was decided in any case to attempt to learn first something about the underlying reason for the occurrence of one type of twin rather than another. A smaller formation was therefore studied in greater detail—one showing a variable composition.

Several petrographers³ have noted an apparent connection between the composition of a rock and the twins present. Albite and Carlsbad twinning, for example, though common in all plagioclase, predominate overwhelmingly in rocks containing sodic feldspars. Pericline twinning is a common occurrence in rocks containing calcic feldspars. The conclusion has been drawn that a composition of the crystallized rock in some way is a factor at least, in deciding the twinning laws which may develop. If this is true, then twinning is robbed of any apparently useful meaning. If not true, then the underlying controlling factors invite investigation. The present study outlines the relationship between twinning and composition as revealed in an occurrence which is believed to be favorable for the purpose.

A diabase sill outcropping in Concession 1, lot 12, Bridgland Township, District of Algoma, Ontario, was chosen for study. The sill shows differentiation to a considerable degree, and therefore affords an opportunity to compare the feldspar twins present with more than one compositional rock type, under conditions such that the variable factors within the range of rock types are at a minimum.

A detailed description of the sill and a chemical study of its differentiates has already been published.⁴ A fresh suite of specimens was collected for this study, with the present purpose in mind. Over the measured thickness of 1100 feet specimens were taken. Thin sections were cut from these.

Some pertinent details for this discussion may profitably be repeated

² Specimens were obtained through the courtesy of Margaret Fuller Boos, *Bull. Geol. Soc. Am.*, vol. 45, pp. 303-332, 1934.

³ Gysin (17) (18) (19), Coulson (5), and Lodochnikov (25), have attempted to correlate twinning and composition. More frequently, however, accounts noting both phenomena, such as those of Herrmann (20), Vendl (46), and Kolaczdzowska (23), lack this effort to find a specific significance for twinning. Another group have placed entire emphasis on twinning, but merely list the number of twins according to the various laws. Examples may be found in the works of Azzini (1), Baier (2), Carrasco (4), Dolar-Mantuani (7), Drugman (8), Duparc (10), Lewis (24), Palinc (34), Sabot (39), Schlossmacher (40), Solinac (42), and Wieseneder (50). Finally, there are those who note twinning incidentally to their other studies as: Diehl (6), Duparc (9), Ghika-Budesti (15), Jahn (21), Johs (22), Maroscheck (29), Riba (37), Spencer (43), and Wang (49).

⁴ Emmons, R. C., *Am. Jour. Sci.*, vol. 13, p. 73, 1927.

here. A slightly aschistic zone is present at the lower contact. A shear zone crosses at approximately 262 feet above the base. The main body of the sill is typically diabasic, medium grained, and has a poikilophitic texture. A coarse pegmatite enters near the top of the sill, but was avoided in sampling. Red feldspars become evident near the upper portion, giving the rock a slightly pinkish hue. Pyroxenes are the dominant ferromagnesian minerals, but are altered to amphibole in the shear zone and the upper portion of the sill. Biotite and epidote tend to be concentrated in the upper phases, however veins of epidote are also present in the aschistic zone. Quartz, with a vermicular texture, likewise is found in the aschistic zone and not again until the upper portion is reached where graphic texture is prominent. The feldspars throughout the lower and main portion of the sill are generally free of alteration, and many exhibit strain and zoning. Near the top and in the shear zone they are extremely sericitized and chloritized. In the lower portion of the sill there are more than twice as many feldspars as other mineral crystals, while in the upper portion there are less than half as many feldspars. In composition they range from bytownite (An_{75}) to oligoclase (An_{32}).

METHOD OF STUDY

The feldspar twinning laws and compositions were determined in thin sections with the aid of the universal stage. Most of the determinations were done by Rittmann's Zone Method⁵ (38) which is satisfactory in the majority of cases. It fails when the composition is over 75 per cent An. It fails also in making a reliable distinction between Manebach Ala A twins and Manebach-akline twins. Likewise, in the acid feldspars of about 28 per cent An content there is difficulty in distinguishing between albite and albite Ala twins, as has been pointed out by Manolescu (28).

When it was impossible to use Rittmann's method and also as a check on that method, the procedure of Fedorov-Nikitin⁶ (11) was followed. This involves more time but gives more accurate results; therefore, several twins in each thin section were determined by this method in order to check the results found by that of Rittmann. The only limitation here is in the width of the twin lamellae, the very narrow ones being impossible to orient if they disappear from view on inclination of the inner stage. Since a considerable part of the work employed the Fedorov-

⁵ This is a method whereby the composition plane of a twinned feldspar is oriented vertical and parallel to the N-S axis, and critical extinction angles are read from a known recognizable direction in the composition plane.

⁶ This is the original method of Fedorov consisting of plotting critical optical data for two or more lamellae on a stereographic projection. The relationship between lamellae thus brought out discloses the twinning axis. The attitude of the twinning axis relative to any crystallographic datum plane discloses the twinning law and composition.

Nikitin method, the modified universal stage was used, which greatly simplifies the procedure and lessens the time required for its manipulation. The modified stage offers no advantages for Rittmann's method.

Coulson (5) has demonstrated by means of projections on (010) that there is a possibility of confusing albite Ala B twins of 33 per cent An with Albite-Carlsbad twins of 0.5 per cent An; however, this limitation hardly enters into the present study.

By means of the above procedures an attempt was made to determine the twin laws of every twinned feldspar in each thin section, all

PROPORTION OF TWIN LAWS AT DIFFERENT HORIZONS IN A SILL

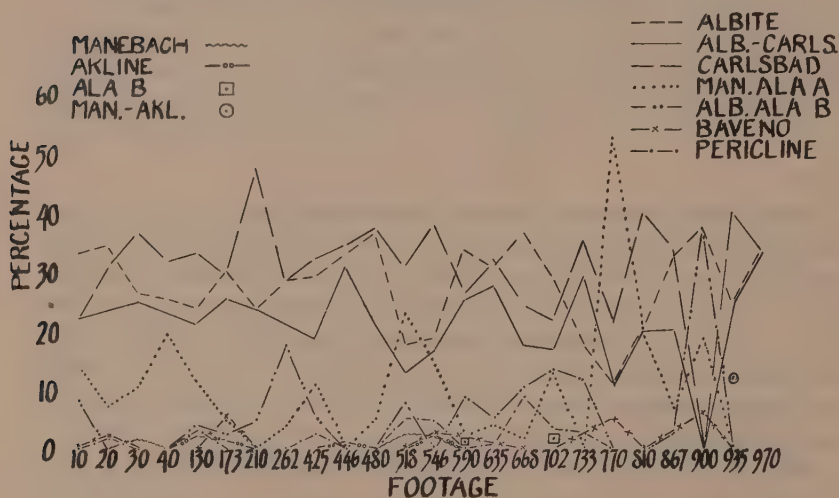


FIG. 1

thin sections being approximately the same size. The results are given in table 2 and figure 1.

Having determined the twin laws, statistical methods were then used in order to express the relationships in more exact terms than is otherwise possible. These appear in tables 3 and 4, and figures 3 and 4.

The composition was determined on an average of ten of the twinned feldspars studied in each thin section. Compositions were found by means of extinction angles on Rittmann's figures, and were checked on the twin-axis curves of Fedorov's projections. Manolescu (28) has shown that the composition plane is apt to be made up of vicinal faces and therefore does not afford a reliable An content determination. For this

reason the twin-axis curves of Fedorov's diagrams as corrected by Nikitin's later data (13) (33) were used. Projections of [001] give still more accurate results but are not always available and are more difficult to use.

The composition selected as representative of the thin section was the average of all found by the above two methods, a range of about 10 per cent having been present in each slide.

A further check on composition was made by the totally different Tsuboi (45) method. This involves chipping off a feldspar cleavage flake, immersing it in a liquid of approximately the same index, and finding the refractive index of the fast ray for this orientation.

The results from the above two methods are plotted on figure 2, together with a general average of the two groups of data.

AN CONTENT THROUGHOUT A DIFFERENTIATED SILL

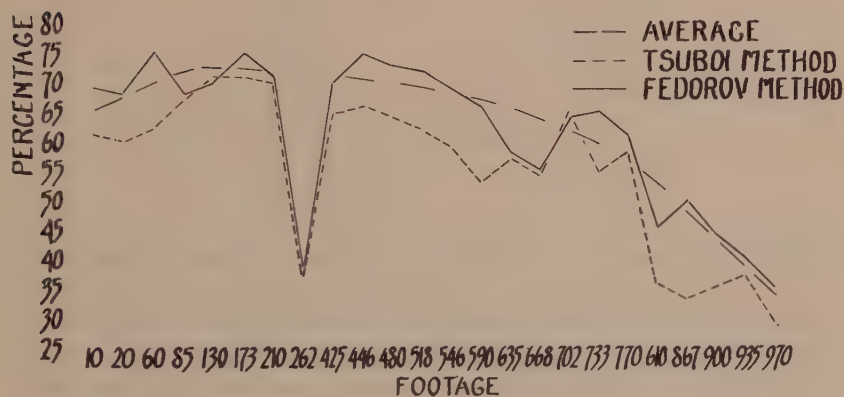


FIG. 2

DISCUSSION

The following conclusions represent earlier attempts to find a reason for specific twin occurrence: pericline twinning is most closely associated with plutonic rocks (18) (35), akline twinning is confined mainly to effusive rocks (18); albite twinning is predominant in albite, and Carlsbad twinning in oligoclase feldspars (25). However, when the findings of several writers are tabulated, as in table 1, showing the least and greatest anorthite content at which a given twinning law is found, it will be seen that each law is found throughout a fairly wide range, and not confined to any given composition.

The following discussion, though not solving the problem, does eliminate from this occurrence certain factors which formerly were thought to control twinning. Table 2 and figure 1 indicate that although each twin law varies in frequency from bottom to top of the sill, its average would not digress markedly from a straight line. No twin is found in only one section of the sill; the acidic upper portion contains about the same types of twins as the more basic lower portion. An exception may be noted in the last two sections which lack the more rare twin types, and the latter of these two sections also is the only one containing Mane-

TABLE 1

Twin Law	Upper and Lower Limit An Content
Carlsbad	0-73
Albite-Carlsbad	0-73
Albite	0-73
Ala	1-75
Pericline	22-90
Manebach Ala	50-63
Manebach-akline	20-64
Baveno	23-40
Albite Ala B	35-80

References: (46) (50) (20) (23) (17) (19) (5) (11)

bach-akline twinning. However, little weight can be given to these exceptions because: alteration of the feldspars is so heavy in this portion of the sill that the chance for error in orientation by any method is very great; the total number of twins is not large; those which could be oriented were so few in number that all classes could not be filled; and there is difficulty in distinguishing between Manebach Ala A and Manebach-akline by Rittmann's method, which had to be used here on account of the narrowness of the lamellae.

The common belief that certain twins occur more frequently in acid rocks than in basic, and vice versa, is brought out by the works of Coulson (5), Gysin (17) (19), Phillips (35), and Lodochnikov (25). This differentiated sill, having a slightly aschistic phase in the lowest portion which verges into a normal diabase with a gradually more acidic upper portion, gives a great enough range in composition to show if there is a tendency for any twinning law to be specifically associated with a given composition. Such a tendency is, however, not apparent from these data. Any twin given in table 2 may be traced from bottom to top of the sill even though there is variation in frequency from section to sec-

tion. (An exception is the Ala B and Manebach twins which occur so rarely that no conclusion may be drawn.) The shear zone represents a sudden, very acidic phase in the sill as is shown in figure 2. This zone emphasizes that no types of twinning are to be more closely correlated here with composition than other types.

TABLE 2. NUMBER OF TWINS

Foot- age	An %	Alb.- Carl.	Carl.	Alb.	Man. Ala A	Alb. Ala B	Bab.	Akl.	Ala B	Per.	Man- akl.	Man.	All Twins
10'	69	8	8	12	5	3							36
20'	68	26	34	38	8		2			2			110
60'	75	17	25	18	7							1	68
85'	68	11	15	12	9								47
130'	70	28	42	30	14	5		3		4			126
173'	75	32	37	38	6	3	7	2					125
210'	71	5	10	5		1							21
262'	38	6	8	8	1	5							28
420'	70	7	12	11	4	2				1			37
446'	75	58	64	61				2					185
480'	73	17	30	29	4								80
518'	72	5	12	7	9	3				2		1	39
546'	69	7	16	8	6		1	1		2		1	42
590'	66	23	24	31	2	8	2		1				91
635'	58	25	31	30	4	5	1			1			97
668'	55	10	14	21	1	6				5			57
702'	64	10	13	17	8	8			1	2			59
733'	65	10	12	6		4	1			1			34
770'	61	2	4	2	10		1						19
810'	45	1	2	1	1								5
867'	50	12	20	19	4	2	2						59
900'	44	0	0	6	3	6	1						16
935'	40	6	10	6							3		25
970'	35	1	1	1									3
													1406

In order to secure sufficiently large numbers in each class, twins, from adjacent specimens, of similar composition from different horizons were grouped together, care being taken not to break up petrographic relationships. The 10-20 foot group-level was then correlated with each succeeding group-level as shown in table 3. The coefficients of correlation (r) between the lowest (10'-20') level and each of the other group-levels are very high. This means that this level (10'-20') is very similar to each other level. Because the coefficients of correlation are not directly comparable they are given in squared form in figure 3. These expressions,

COEFFICIENT OF DETERMINATION SHOWING THE RELATION BETWEEN THE 10-20 FOOT GROUP-LEVEL AND OTHER LEVELS

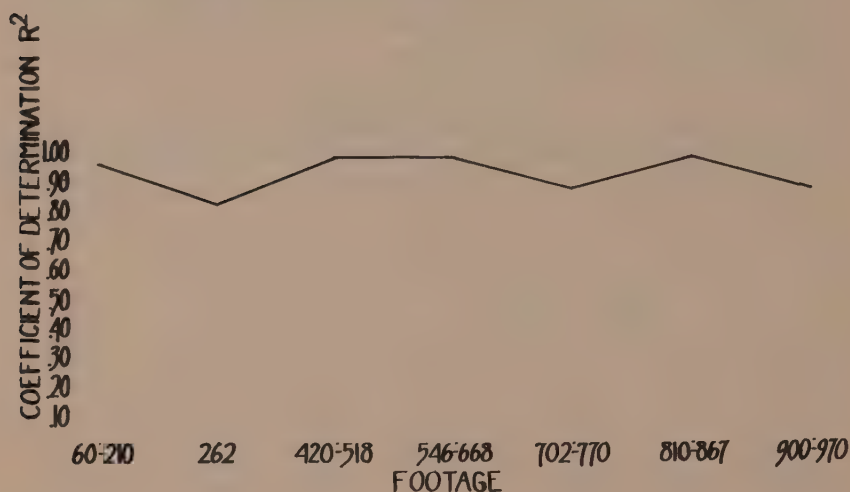


FIG. 3

(r^2), termed coefficients of determination, are proportional to each other and therefore can be treated as percentages. In this analysis they are used in a manner similar to that reported by Dryden⁷ for heavy minerals; that is, to measure the similarity of the proportions of different twinning laws in the two group-levels correlated. By dividing the sill into these groups representing various compositions, it is shown that the type of twinning is much the same throughout the sill regardless of change in composition.

TABLE 3. CORRELATION BETWEEN PROPORTION OF TWIN LAWS AT GROUP-LEVEL 10'-20' AND OTHER GROUP-LEVELS

Group-Level	Number of Twins	Correlation Coeff. with 10'-20' Level	Coeff. of Determination
60'-210'	337	0.976	0.953
262'	28	.903	.810
420'-518'	341	.985	.970
546'-668'	287	.986	.972
702'-770'	112	.923	.852
810'-867'	64	.984	.968
900'-970'	44	.922	.850

⁷ Dryden, L., A statistical method for the comparison of heavy minerals: *Am. Jour. Sci.*, vol. 29, no. 173, p. 393, 1935.

In order to study the variations of each twinning law more specifically, correlations between the anorthite content and frequency of type of twinning,⁸ as well as the total number of twins, were calculated. The An content and the total number of twins show a highly significant positive correlation (table 4). Toward the more basic wall of the sill, the relative number of twinned feldspars increases. Therefore, it is important to know whether the increase in total number is the result of a marked increase in only one twinning law, or whether it is proportional for all laws. If proportional, then no twinning law shows a definite association with a specific composition; if not proportional, then some twins must occur relatively more often at a given composition. Each correlation for the

TABLE 4. CORRELATION BETWEEN TWIN LAWS AND ANORTHITE CONTENT

Type of Twin	Number of Twins	Correlation Coeff. with An Content	Probability	Coeff. of Deter.
All twins	1406	0.505	± 0.01	0.255
Alb.-Carls.	326	.472	± 0.02	.223
Carlsbad	443	.493	± 0.01	.243
Albite	416	.441	± 0.04	.194
Man. Ala A	106	.410	± 0.05	.163
Albite Ala B	61	-.197	>0.05	.039
Baveno	18	.157	>0.05	.025
Akline	8	.368	>0.05	.134
Pericline	20	.099	>0.05	.009
Manebach	3			
Ala B	2			
Man.-akline	3			

more common types—Carlsbad, albite, albite-Carlsbad, and Manebach Ala A—is significant and of about the same order as the correlation between An content and total number of twins (table 4). This means that each type of twin increases with increasing An content and to about the same extent. In other words, the increase of each is proportional to the increase of the total number of twins. The rarer twins, on the other hand, show an insignificant correlation, and would probably occur more than 5 per cent of the time by chance. This may be due to the few numbers in these classes, or to the fact that these twins are scattered at random with relation to the An content and therefore at random throughout the sill. The coefficients of determination are shown graphically in figure 4.

⁸ Manebach, Ala B, and Manebach-akline twins were not included because they were present in such small numbers.

The cause of twinning in feldspars is generally conceded to be differential stress (44) applied to the crystal at any time but usually in igneous rocks at or near the time of crystallization. Some metamorphic rocks show feldspar twinning which appears to be a modification of original twinning. Further work on metamorphic suites suitable for this purpose should yield interesting results. Mutual interference of growing crystals is probably a most common cause of the stresses required. It appears to be true, however, that although differential stress is the cause of twinning, there are other factors which are extremely important in deciding what twins shall respond to the stresses present. This other con-

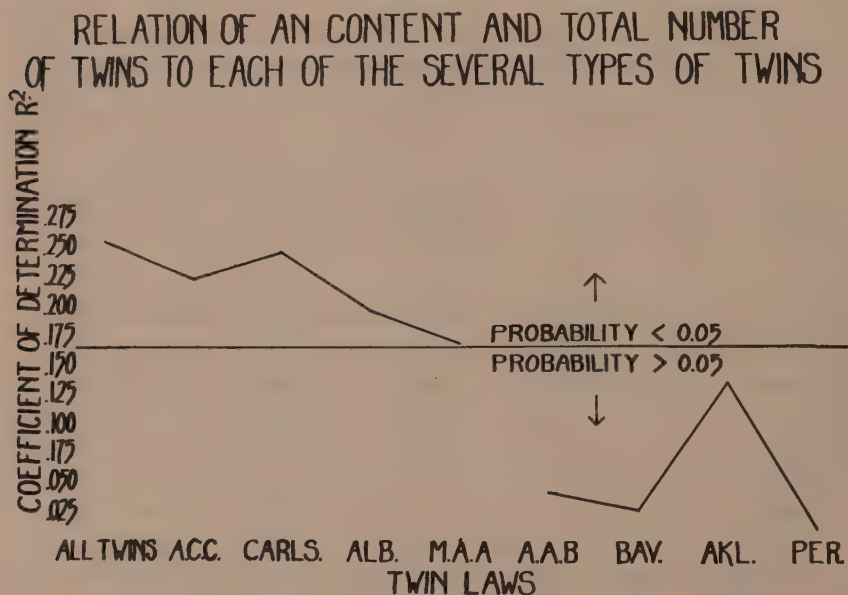


FIG. 4

trol is the object of our present interest. It has been attributed to composition of the rock in some unknown way as indicated above. The facts brought out in this study militate against this view unless by composition is meant the composition of the magma rather than the rock as we know it.

It is hoped by a process of further elimination to learn more about the nature of these controlling factors. There is need for further confirmatory information of the type presented here. Needed, also, is more information on the nature of the differences in twins between igneous and metamorphic rocks. And it is especially desirable to learn the extent to which twinning may vary from point to point in one rock body.

Parenthetically attention may be called to two interesting sidelights encountered during the present study. The first is brought out in figure 2 which shows the apparent discrepancy in measurements of composition by Fedorov's and Tsuboi's methods. Mention has been made that an apparent range of 10 per cent in composition is evident from Fedorov's method. So persistent is information of this sort that it seems necessary to assume either that contiguous feldspars vary in composition or optical methods have limitations which are not generally admitted.

TABLE 5. COMPARISON OF TWINS IN DYNAMITED AND UNDYNAMITED ROCK

	Micro- cline	Albite	Carl.	Alb.-Carl.	Albite Ala B	Man.- akline	Total
(F ₁) No.	26	19	10	7	4	3	69(T ₁)
Dyn. %	37.68	27.54	14.49	10.14	5.80	4.38	
(F ₂) No.	44	20	9	4	1	0	78(T ₂)
Undyn. %	56.41	25.64	11.54	5.13	1.28	0.00	
Total No. (Ti)	70	39	19	11	5	3	147

$$\begin{aligned}
 &^*1/\text{Ti}(\text{F}_2 \times \text{T}_1 \\
 &\quad - \text{F}_1 \times \text{T}_2)^2 = 14515 \quad 267 \quad 1331 \quad 6627 \quad 11810 \quad 18252 \\
 &\Sigma 1/\text{Ti}(\text{F}_2 \times \text{T}_1 - \text{F}_1 \times \text{T}_2)^2 = 52802 \\
 &\text{X}^2 = \Sigma 1/\text{Ti}(\text{F}_2 \times \text{T}_1 - \text{F}_1 \times \text{T}_2)^2 = 52802/5382 = 9.81 \\
 &\text{therefore } P \approx 0.10
 \end{aligned}$$

* Formula derived from Fisher's work. Fisher, R. A., *Statistical Methods for Research Workers*. 3d Edition. Oliver and Boyd, *Edinburgh and London*. Pp. 75-98, 1930.

The second sidelight developed from a brief study made on slides which were generously loaned by Professor E. Blackwelder. One slide represents granite which was dynamited in the Yosemite Tunnel, the other, undisturbed granite "from a small quarry in the same formation as that pierced by the Yosemite Tunnel and less than half a mile due north from it. I think very little blasting has been done in the quarry as the rock is well jointed."⁹ It was thought that a comparison of these rocks would reveal any possible influence on twinning which such pressures as dynamiting could produce. A statistical study of the twins showed (table 5) that the proportions of the different twins did not differ significantly in the two slides. The effect on twinning is, therefore, not measurable though the rock itself was badly shattered. (The distance between the two specimens is considerable, but satisfactory for negative results.)

⁹ Quotation from letter.

The writer is greatly indebted to Professor R. C. Emmons who suggested this study and under whose direction the work was done.

SUMMARY

The intensive study of feldspar twinning by earlier workers has revealed much about the nature of twinning and its occurrence, but has led to virtually no understanding of the ultimate factors which decide which twinning law shall develop. Nor has any practical use been made of this twinning.

A few authors have suggested that certain twinning laws may be restricted to a specific anorthite content of feldspar. Several have called attention to the common differences in frequency of twin-law occurrence in granites and gabbros.

It has been tentatively believed by many that the composition of the feldspar or of the rock, was a controlling factor in deciding which twin-law should occur.

The present study shows that *in a differentiated sill ranging in feldspar composition from An_{75} - An_{32} the relative frequency of occurrence of one twinning law with respect to another is essentially constant*. This does not hold for the rarely occurring laws. So few of these were found, however, that the lack of agreement for the rare laws is only a tentative conclusion and applies only to this study.

The apparent difference in twinning in granite and gabbro remains unexplained. Further studies will be directed toward its solution.

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THE MINERALOGY OF ASBESTOS

ISHKYLDITE, A NEW STRUCTURAL VARIETY OF CHRYSOTILE

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ABSTRACT

Among the different varieties of asbestos, studied by the author, one specimen showed a number of peculiar properties: in appearance it resembled actinolite-asbestos; in chemical composition it was found to be very near chrysotile-asbestos, while in optical properties it approached antigorite. All the characteristics named, and particularly a peculiar atomic arrangement, permit this asbestos to be singled out as a new mineral, the name of which—*ishkyldite*—has been derived from the locality of its occurrence.

In 1932 in the environs of the village of Ishkyldino (the Orskho-Khalilovo region of the Middle Volga District) engineer Fedorov was prospecting for chrysotile-asbestos deposits in serpentinites. The specimens belonged to the slip-fiber type. Among them two varieties were found. Specimen No. 1 (Adit No. 1) is a slip fiber chrysotile asbestos of the usual appearance, which I have classed with β -chrysotile (1). This specimen was correctly identified by the author at sight, and a further study only confirmed this determination.

Specimen No. 3 (Adit No. 1) was so unusual that at first it was mistaken for an asbestos of the amphibole group. An imperfect fibering, a greasy feel and a low mechanical strength favoured this impression. A slightly greenish colour pointed to a higher iron content. On the strength of these properties the specimen was thought to be actinolite asbestos. A study of the chemical composition showed this identification to be erroneous. An x-ray study has solved the problem and proved that the substance is a new mineral. From the locality of its occurrence it has been named *ishkyldite*.

Macroscopically, the mineral is characterized by the following features:

It is faintly coloured. The colour of the compact specimen is silvery-bluish-green. Upon fiberization the colour of the mineral becomes still lighter. Its hardness is one. It has a greasy and soft feel. It is easily torn, and is fiberized with difficulty, although it can be readily split into separate fibers. It has a fairly well defined parting,¹ which may sometimes be used for obtaining fairly good laminae from the specimen. The specimen described contains inclusions of magnetite, distributed sporadi-

¹ Among the specimens collected by eng. M. P. Lozhechkin I succeeded in establishing the presence of a specimen of *ishkyldite* with a sharply defined parting. Along this parting the mineral can be readily split into laminae. The fibering of this specimen is similar to that of the one described.

cally, and is in some places stained with iron oxides. The specific gravity is 2.62. In chemical composition ishkyldite is a typical serpentine, as shown by the chemical analysis given in Table 1. A recalculation of the analysis yields a formula, approaching the theoretical. Thus, if we assume it to be $H_4Mg_3Si_2O_9$, an excess of SiO_2 of 3% by weight is obtained. This value exceeds greatly the permissible error of the analysis.

TABLE 1. CHEMICAL COMPOSITION OF ISHKYLDITE

	Per cent		Per cent
SiO_2	42.49	H_2O+	11.88
Al_2O_3	1.27	H_2O-	0.79
Fe_2O_3	2.01	CO_2	0.35
FeO	2.73	TiO_2	trace
MgO	38.28	MnO	0.06
CaO	0.00	Cr_2O_3	trace
Na_2O }	0.02	NiO	0.38
K_2O }		Volatiles	0.04
		Total	100.30

Analysts: P. I. Vasiliev and I. I. Romm

The following empirical formula conforms more nearly with the analysis: $H_{20}Mg_{15}Si_{11}O_{47}$. From the above it is seen that the composition of ishkyldite is characterized by a greater quantity of silica (about one additional molecule of SiO_2 to each 5 molecules of serpentine). It is interesting to note that the author (1) has previously established an excess of silica also for β -chrysotile.

Thus, from its chemical analysis, ishkyldite is to be placed in the chrysotile-asbestos group. A high content of ferrous iron (almost 3 per cent) would incline us to refer it to the group containing brittle asbestos (1). Ishkyldite, in fact, has also a low mechanical strength. Its optical properties and structure, however, are so different, that we have decided to call it an independent variety.

As shown by an x-ray photogram, made by K. V. Vasiliev at the x-ray laboratory of the Institute, the atomic arrangement of ishkyldite is different from that of α -chrysotile (1). No detailed study of the structure has as yet been made. But a measurement of the identity period along the fiber axis has been carried out. In Table 2 the condensed results of calculations, made by the author, are given. (The radiation used, Molybdenum-K series.)

From this table it is seen that the identity period of ishkyldite is nearly twice as great as that of α -chrysotile. The distribution of spots is also different. Consequently, ishkyldite is a new structural modification of chrysotile.

TABLE 2. IDENTITY PERIOD OF ISHKYLDITE

Order of layer line	Radiation	Identity period
1	α_1	9.77Å
2	α_1	9.76
3a	β_1	9.66
3b	α_1	9.60
4	—	—
5	—	—
6a	β_1	9.62
6b	α_1	9.66
Arithmetical mean		9.678Å

The optical constants of ishkylidite are as follows:

$$N_o = 1.573, N_p = 1.566$$

$$N_o - N_p = 0.007; 2V = 58^\circ.$$

The optic angle was measured by the author on the Fedorov stage. The plane of the optic axes is oriented parallel to the fibers and perpendicular to the parting planes (see Fig. 1).

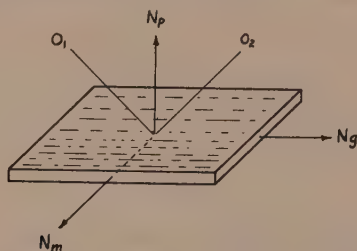


FIG. 1. Orientation of the index ellipsoid in ishkylidite.

The optical properties of ishkylidite are such as to present an interesting subject for speculation and investigation.

Being finely fibrous this mineral is a two-dimensional colloid. The theory of the optical properties of colloids has been developed by Wiener (2), Frey (3), Möhring (4), Lichtenecker (5), Ambronn (6), Wächtler (7), and others. According to the theory of Wiener (2), the birefringence of a complex body, consisting of particles of a definite shape, and of a medium, in which they are regularly distributed, depends on the relation between the values of the refringence of the particles and of the medium. If we change the properties of the medium, the birefringence will be changed also.

Let us attempt to apply this theory² first to the more fully investigated α -chrysotile.

² Calculations are omitted.

The intermediate medium for this mineral is probably the absorbed water, filling the interstices between the elementary fibers. Its refringence must be lower than that of chrysotile. The integral index of refraction will lie between the refractive index of water and that of chrysotile. As the fibers of chrysotile are continuous throughout their length, the refractive index N_p must remain constant and independent of the surrounding medium. Hence, we shall be interested chiefly in the optic vector of the section across the length of the fiber. The absorbed water is probably isotropic. We do not know exactly what are the values of N_m and N_p of chrysotile. But this has been found to be of no consequence, since the resulting optic vector will not depend on the direction (9), due to occasional turns of elementary fibers around the direction of fibering. Applying now the theory of Wiener, we are brought to the conclusion that chrysotile is a uniaxial mineral.

All these reasonings are equally applicable³ to ishkyldite, as this result cannot depend on the atomic arrangement. Ishkyldite, however, is not a uniaxial, but a distinctly biaxial mineral. Its x -ray photogram reveals a regular fine-fibered texture. The latter may exist only when the elementary fibers are oriented in one single direction. Any, even partial, orientation in some other direction would immediately affect the x -ray photogram. Consequently, it is not here that the solution of the said controversy is to be sought. In my opinion it is necessary to turn our attention to the interspaces between the elementary fibers. In chrysotile they are assumed to be equal in all directions, and probably such is actually the case, as the splitting capacity of chrysotile-asbestos does not depend on the direction.⁴

Such is not the case with ishkyldite. It is highly probable that stress has favored the formation of unequal spaces between the "layers" of the fibers. The presence of parting indicates that definite rows of fibers are separated by a greater distance than the individual elementary fibers. If we make a cross section of an ishkyldite fiber and represent the location of the elementary fibers by black dots, a diagram results, shown in Fig. 2. It is a kind of secondary laminated lattice.

Since the value of $m > n$ (see Fig. 2), it is clear, that the forces of cohesion will be changed accordingly. Hence the formation of the parting plane. The same factor must play a part also in forming the integral optic vector. To the extent that the elementary optic vector of the surrounding medium (absorbed water) will play a greater rôle in one direction, and a lesser in the direction normal thereto, the integral optic

³ If between the fibers some other isotropic medium, e.g., air, is present, the result will not be different.

⁴ We mean the directions lying in the plane, perpendicular to the length of the fiber.

vector will be dependent on the direction. Hence, the mineral will be biaxial. This is not all, for in addition the location of N_p and N_m may be predicted. As water must have, as mentioned above, a lower refractive index than that of the mineral, it is easy to understand that the optic vector perpendicular to the parting must be a minimum, i.e., it will be N_p . Therefore, the plane of the optic axes must be parallel to the length of the fibers and perpendicular to the parting plane. Fig. 1 shows us that we have this optic orientation in ishkyl-dite.



FIG. 2. Diagram showing texture of ishkyl-dite (cross section); black dots show locations of elementary fibers; $a-a$ =direction of parting plane.

In a previous paper (1) I have shown, that the small amount of this mineral did not permit me to obtain entirely definite data from the thermal analysis. Still, the following peculiarities may be noted for the thermogram of our specimen:

- (1) an indistinct endothermal peak at about 100°C.;
- (2) a complex endothermal double peak, with apexes at 650° and 710°C.;
- (3) a distinct exothermal peak at about 800°C.

A heating curve of such a nature resembles that of the semi-brittle type of α -chrysotile. The difference lies in the lower values of the temperatures of the complex peak. As shown previously (1) the existence of such a peak may be, in my opinion, related to the presence of fibers of asbestos of another kind (for the brittle type of α -chrysotile). Ishkyl-dite, in fact, contains nearly three per cent of ferrous oxide, and therefore a certain analogy with brittle asbestos may be established. We have no data, however, to arrive at a conclusion as to the heterogeneity of ishkyl-dite. Here too, as in the case of semi-brittle asbestos (1), the reason of the said phenomenon is to be sought in the peculiarities of the inner structure of ishkyl-dite.

The specimen from Karabash (M. P. Lozhechkin's collection) is on the whole identical with the author's specimen in its properties; but on its thermogram only one of the two apexes of the complex endothermal peak is distinctly visible. It corresponds to a temperature of 700°C. There are but faint indications of the other peak. All the endothermal changes

of ishkyldite caused by the removal of water were shown by the preliminary experiments carried on by V. N. Mishina under my supervision, using the method of absorption—thermal dehydration (10). The amount of water given off at various temperatures is shown in the following table. The dehydration at every stage was made at constant temperature until the water had ceased to be evolved. The amount of water was determined from the weight of the absorption tubes filled with P_2O_5 . For carrying off the water vapours a stream of dry air was slowly passed through the apparatus. Table 4 shows that the "combined" water is given off not at one but at several temperatures, which is in keeping with the above description of the large endothermal peak.

TABLE 4

t°C.	Time of dehydration	Per cent of water
	in hours	evolved
100	3.4	0.60
200	3.2	0.00
300	2.5	0.16
400	2.8	0.11
500	3.5	0.54
530	8.4	1.50
600	9.5	7.14
700	4.0	1.60
		<hr/>
Total		11.73 per cent

It may be stated, therefore, that the behaviour of water in ishkyldite when heated is more complex than in α -chrysotile of a normal type. I have as yet found no explanation for this fact.

As to the origin of ishkyldite, owing to lack of observations of my own, little can be said at present.

There is no doubt that ishkyldite grew under conditions of stress, directed perpendicular to the axis of the fibers. I do not know as yet how it was oriented with respect to the side walls of the fissure. It is beyond doubt, however, that this direction must have lain in the plane perpendicular to them, since the axis of the fibers of ishkyldite is oriented parallel to the walls of the fissure. It is also clear that ishkyldite could not have been formed by crumpling of α -chrysotile, since it has a different atomic lattice. Finally, it is necessary to assume a somewhat different composition of the parent solutions. A somewhat earlier formation of ishkyldite as compared with α -chrysotile may also be assumed since the latter must have been formed when the mechanical strains had been sufficiently weakened, as is usually the case in a later phase of the history of the massive rock.

SUMMARY

1. Ishkyldite, as shown by its chemical and x-ray analyses, is a new mineral and represents a structural modification of chrysotile.

2. Its composition is expressed with sufficient accuracy by the empirical formula: $\text{H}_{20}\text{Mg}_{15}\text{Si}_{11}\text{O}_{47}$.

3. The optical properties of ishkyldite are as follows:

$$N_o = 1.573, N_p = 1.566;$$

$$N_o - N_p = 0.007; 2V = 58^\circ.$$

4. A theoretical explanation is given of the nature and orientation of the optical ellipsoid.

5. The identity period of ishkyldite in the direction of the axis of the fibers is $C = 9.68 \text{ \AA}$.

6. The specific gravity is 2.62.

7. The thermal analysis and the dehydration of this mineral shows distinct peaks.

8. Ishkyldite is probably an earlier mineral than α -chrysotile (chrysotile-asbestos). Characteristic of the conditions of its formation is the existence of stress at the time of growth.

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CUBANITE FROM SUDBURY, ONTARIO

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SUMMARY

Excellent crystals of cubanite from Sudbury, Ontario, are orthorhombic, dipyramidal, with the forms: $c(001)$, $b(010)$, $a(100)$, $l(130)$, $m(110)$, $e(012)$ new, $\gamma(011)$, $f(102)$, $g(101)$, $d(201)$, $t(112)$, $w(111)$, $o(122)$, $r(121)$, $p(131)$, on the preferred pseudo-hexagonal parameters of chalmersite: $a:b:c=0.5822:1:0.5611$ (Hlawatsch). Twins, common by reflection in (110); also by rotation through $119^{\circ}35'$ about [001]. Cleavage, none; $H=3\frac{1}{2}$; $G=4.101$ at 27°C ; magnetic, highly susceptible along [010]. Analysis: Cu 22.88, Fe 41.41, S 35.35; sum 99.64, giving CuFe_2S_3 . The identity of cubanite and chalmersite is confirmed. The name chalmersite should be dropped. It is suggested that the name barracanite may be revived for the mineral with composition CuFe_3S_4 , if such exists.

The Harvard Mineralogical Museum recently received a specimen with excellent crystals of cubanite of novel appearance from the Frood Mine at Sudbury, Ontario. The specimen was collected in the course of an investigation of the ore deposits of that district, by the Department of Geological Research of the International Nickel Company of Canada, Limited. We are indebted to Dr. H. J. Fraser of the department for this interesting material and to the management of the company for courteous permission to publish our observations and the accompanying analysis. The crystallographic study is largely the work of the junior author; it was revised and completed by the senior author who has added the remaining material. Our thanks are due to Professor Charles Palache for the privilege of studying this material and for advising us in the course of the work, and to Professor L. C. Graton for reading the manuscript and suggesting some improvements.

CRYSTALLOGRAPHY

The Sudbury cubanite is brassy yellow and the crystals are of substantial size, up to 5 mm. across, and not greatly elongated in any one direction. In this respect the Canadian crystals differ from the prismatic crystals of chalmersite¹ from the Morro Velho Mine at Minas Geraes in Brazil, described by Hussak (1902), Palache (1907) and Hlawatsch (1910). Some of the Sudbury crystals are thick basal tables somewhat elongated along the b -axis; some are flattened between a pair of parallel

¹ The investigations on *Cuban* (Breithaupt, 1843) and *Chalmersit* (Hussak, 1902) are examined by Zenzén (1925), who reaches the well-founded decision that the minerals described as cubanite or chalmersite are identical, and that cubanite has priority. The deciding observation is that of Kalb and Bendig (1923) who identified a polished section of Breithaupt's original material from Cuba with material from Tunaberg, Sweden, which has all the properties of the typical chalmersite from Brazil.

faces of the unit prism and slightly extended along the *c*-axis; and all of them are fully developed on their free sides in holohedral orthorhombic symmetry.

On the two-circle goniometer the crystals give excellent measurements in close agreement with the angles calculated by Hlawatsch from Palache's elements for Brazilian chalmersite in a new orientation. Palache retained the orientation of Hussak, which displayed a morphological analogy between cubanite and chalcocite but resulted in somewhat complicated indices. Hlawatsch interchanged the horizontal axes and took the plane (133) in Palache's notation as the parametral plane. Independently we have reached the same orientation as that of Hlawatsch, which is adopted with Professor Palache's approval. Considerations of morphological analogy may properly decide the arbitrary factors of orientation, such as the naming of the axes in the orthorhombic system; but such considerations should not interfere with the choice of morphological elements entirely proper to the species. If morphological relations exist between two species they may then appear more correctly in nearly aliquot relations of the corresponding elements rather than in near equality.

TABLE 1. CUBANITE. TWO-CIRCLE MEASUREMENTS ON EIGHT CRYSTALS

Forms	No. of faces	Measured		Calculated	
		ϕ	ρ	ϕ	ρ
<i>c</i> (001)	12	—	0°00'	—	0°00'
<i>b</i> (010)	8	—0°10'	90 00	0°00'	90 00
<i>a</i> (100)	3	90 00	90 00	90 00	90 00
<i>l</i> (130)	14	29 45½	90 00	29 47½	90 00
<i>m</i> (110)	11	59 49	90 00	59 47½	90 00
* <i>e</i> (012)	2	—0 04½	15 30	0 00	15 40½
<i>y</i> (011)	12	—0 01	29 17	0 00	29 18
<i>f</i> (102)	4	89 57	25 44	90 00	25 43½
<i>g</i> (101)	6	90 00	43 58½	90 00	43 56½
<i>d</i> (201)	2	90 05	62 53	90 00	62 34½
<i>i</i> (112)	1	59 36	29 09	59 47½	29 08½
<i>w</i> (111)	5	59 48	48 08	59 47½	48 07
<i>o</i> (122)	9	40 39	36 27	40 39	36 29
<i>r</i> (121)	20	40 40½	55 57	40 39	55 56½
<i>p</i> (131)	19	29 49	62 44½	29 47½	62 43½

* New form.

The transformation of the elements and symbols of cubanite is expressed by the following equations:

$a:b:c$ Hlawatsch—Peacock and Yatsevitch = $1/3a:1:c/3a$ Hussak—Palache

$h\ k\ l$ Hlawatsch—Peacock and Yatsevitch = $k\ 3h\ l$ Hussak—Palache

Table 1 gives a summary of the measurements on selected crystals, with the symbols and calculated angles of Hlawatsch. The previous form letters have been retained, with the following desirable changes:

Pk. & Yat. $b\ a\ m\ l$

Hlaw. $a\ b\ l\ m$

All the described forms of cubanite were observed by us except:

$h(032)$ Hlaw. = $h(102)$ Pal., unpublished observation by a student.

$s(221)$ Hlaw. = $s(263)$ Pal., a well-established form.

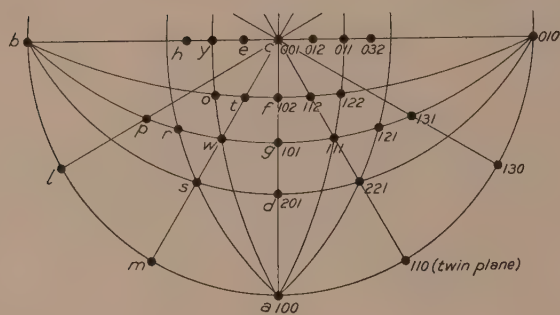
$v(132)$ Hlaw. = $v(112)$ Hus., a presumed and unproved twin plane, never observed as a crystal form and therefore omitted from the form list.

$u(314)$ Hlaw. = $u(1.9.12)$ Pal. Hlawatsch (1910) suggested that this plane, observed only once, is possibly a face of the common form $o(122)$ twinned on (110) or (130). Re-examination of the Morro Velho crystals, on which the form u was reported, revealed evidence of twinning which was not previously noticed. On Professor Palache's suggestion the form is withdrawn.

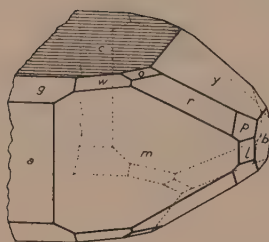
Our measurements confirm the form $w(111)$, observed only by Hlawatsch, and $d(201)$, observed only by Palache and regarded by Hlawatsch as possibly representing $p(131)$ in twin position. One new form $e(012)$ was observed twice, with good small faces in fair position.

The principal forms of the Sudbury cubanite are: c , m , y , which determine the habit of the crystals. The base c is usually large and always striated parallel to [010] frequently in oscillatory combination with the macrodome f . The prism m is likewise present in large brilliant faces giving faultless reflections. The brachydome y is generally next in size and of excellent quality. Of secondary importance are b , l , a , g , f , p , r ; the least important forms are d , o , w , e , t .

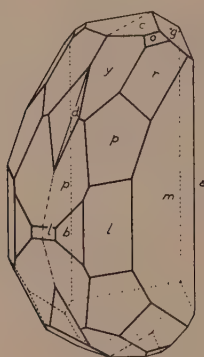
All our crystals are twins in which the planes (001) and (110) are common to the two individuals. On four twins the angle (010): $\overline{(010)}$ was found to range from $60^\circ 21'$ to $60^\circ 27\frac{1}{2}'$; mean $60^\circ 24\frac{1}{2}'$. The calculated angle resulting from twinning by reflection in (110) is $60^\circ 25'$. In most cases the composition surface is the plane (110); occasionally it is a surface near (130). Twinning by reflection in (130), which would result in the calculated angle (010): $\overline{(010)} = 59^\circ 35'$, was not found. Twinning causes the striations on the co-planar bases of the twinned individuals to intersect at about 60° , whereby twinning is easily recognized in the rare cases in which obvious re-entrants are lacking. Most of the twins are binary contact twins on (110) (Figs. 3, 4); one fourling was measured



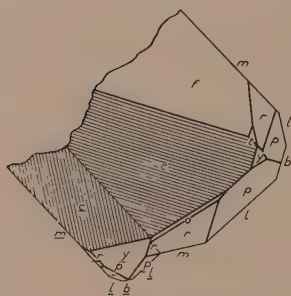
1



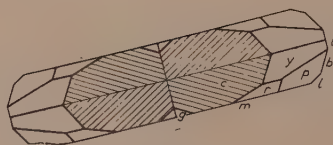
2



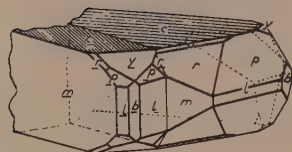
3



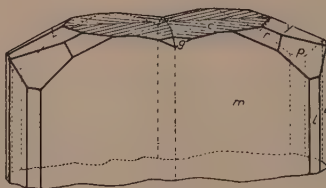
4a



5a



4b



5b

FIGS. 1-5. Cubanite. Stereographic projection of the accepted forms and typical crystals from Sudbury, Ontario.

(figure 5) in which the diagonally opposite individuals are in parallel position while the four adjoining pairs are twins by reflection in (110), or by rotation through $119^{\circ}35'$ or $60^{\circ}25'$ about [001]. One imperfect sixling was observed on the matrix; the striations on the base of each individual make an angle of nearly 60° with those on its neighbours. Although it could not be measured, the sixling is evidently due to twinning on both (110) and ($\bar{1}\bar{1}0$).

Twinning on (130) is implied by Hussak (1902) and Hlawatsch (1910), but in the absence of measurements it is evident that neither author attempted to distinguish between the geometrical relations resulting from twinning on (110) and on the quasi-normal plane (130). The difference in the two twinned positions, namely $0^{\circ}50'$, is much greater than the probable error with these excellent crystals. Still less trustworthy is Hussak's mention, without measurements, of twinning on a pyramidal plane, probably (112) Hussak = (132) Hlawatsch; we measured one such group and found it to be a random intergrowth.

Figure 1 is a stereographic projection of the established forms of cubanite. Figures 2-5 represent typical Sudbury crystals. Figure 2 illustrates a common type developed symmetrically about the *b*-axis; a small individual attached to the main crystal in twin position is omitted in the drawing. Figure 3 is a twin symmetrically developed about the twin plane *m* and flattened parallel to that plane. Figure 4 is an unsymmetrically developed twin on (110), tabular parallel to the base. Figure 5 is a simplified drawing of the fourling mentioned above.

Table 2 is an angle-table for the established forms of cubanite in the style recently proposed by one of us (Peacock, 1934, p. 252). The elements and angles for the inverted positions, with subscripts 1 and 2, are useful in the goniometric study of orthorhombic crystals in which, due to variability of habit, the vertical axis is not easily recognized.

PHYSICAL PROPERTIES

There is lack of agreement in the published data on the cleavage of cubanite (chalmersite). The massive mineral from Cuba and Sweden is described as having cubical cleavage (Breithaupt, 1843; Sjögren, 1882), on which insufficient ground the mineral was originally assigned to the isometric system. Kalb and Bendig (1923) report cleavage as (001) and (110) on Swedish material. On the Alaskan material one good cleavage is reported (Johnson, 1917). On the other hand, cleavage has not been observed on crystals (Hussak, 1902; Palache, 1907; Hlawatsch, 1910), except by Merwin, Lombard and Allen (1923), who broke one crystal from Brazil "squarely along the base." Despite careful trials we failed to obtain any cleavage from the Sudbury crystals; the fracture is

typically conchoidal. It is possible that the conspicuous cleavage in massive cubanite is in reality parting due to polysynthetic twinning on (110). The appearance of rectangular cleavage would result from repeated twinning after the type shown on a large scale by the fourling (figure 5). In such twinning the planes of parting would be the two nearly rectangular composition surfaces (110) and a surface near (130). The lack of agreement on the basal cleavage is not explained.

TABLE 2. CUBANITE— CuFe_2S_3

Orthorhombic, dipyramidal

 $a:b:c=0.5822:1:0.5611$; $p_0:q_0:r_0=0.9638:0.5611:1$ $q_1:r_1:p_1=0.5822:1.0376:1$; $r_2:p_2:q_2=1.7822:1.7176:1$

Forms	ϕ	$\rho=C$	ϕ_1	$\rho_1=A$	ϕ_2	$\rho_2=B$
c (001)	—	0°00'	0°00'	90°00'	90°00'	90°00'
b (010)	0°00'	90 00	90 00	90 00	—	0 00
a (100)	90 00	90 00	—	0 00	0 00	90 00
l (130)	29 47½	90 00	90 00	60 12½	0 00	29 47½
m (110)	59 47½	90 00	90 00	30 12½	0 00	59 47½
e (012)	0 00	15 40½	15 40½	90 00	90 00	74 19½
y (011)	0 00	29 18	29 18	90 00	90 00	60 42
h (032)	0 00	40 05	40 05	90 00	90 00	49 55
f (102)	90 00	25 43½	0 00	64 16½	64 16½	90 00
g (101)	90 00	43 56½	0 00	46 03½	46 03½	90 00
d (201)	90 00	62 34½	0 00	27 25½	27 25½	90 00
t (112)	59 47½	29 08½	15 40½	65 06½	64 16½	75 49
w (111)	59 47½	48 07	29 18	49 57½	46 03½	68 00
s (221)	59 47½	65 51	48 17½	37 57	27 25½	62 40
o (122)	40 39	36 29	29 18	67 13	64 16½	63 11
r (121)	40 39	55 56½	48 17½	57 20	46 03½	51 23½
p (131)	29 47½	62 43½	59 17	63 47½	46 03½	39 31½

The hardness of the Sudbury crystals is $3\frac{1}{2}$, which agrees with Hussak's observation on crystals from Brazil. Merwin, Lombard and Allen found the massive mineral to be harder than chalcopyrite, for which the hardness $3\frac{1}{2}$ –4 is given; Sjögren gives the hardness as about 4, Breithaupt 5.

On a large, clean crystal of Sudbury cubanite Mr. Gonyer reports the specific gravity 4.101 at 27°C., using the silica glass pyknometer. On massive cubanite from Cuba the following values are given: 4.026–4.042 (Breithaupt, 1843); 4.18 (Smith, 1854); 4.169 (Stevens in Dana, 1892). Massive cubanite from Tunaberg, Sweden, gave 4.030 (Cleve,

(1873). Massive chalmersite from Alaska gave 4.04 (Johnson, 1917). On the original crystallized chalmersite from Brazil Hussak (1902) obtained the discordant value 4.680, probably on a minute sample since only 0.015 gm. was used for the corresponding analysis.

The Sudbury cubanite was found to be magnetic and highly susceptible only in the direction of the crystallographic *b*-axis (the *a*-axis of Hussak—Palache), which is evidently the greatest axis of a strongly elongated magnetic ellipsoid; this observation confirms that of Merwin, Lombard and Allen (1923) on Brazilian crystals of entirely different habit. Furthermore, this axis was found to have polarity with respect to a permanent magnet. This raised the question: is cubanite hemimorphic? It proved, however, that the magnetic polarity of a crystal was easily reversed in the field of an electro-magnet; the magnetic property therefore offers no evidence of asymmetry about (010).

COMPOSITION

Table 3 gives an analysis of the Sudbury cubanite compared with previous analyses of cubanite (chalmersite).

TABLE 3. ANALYSES OF CUBANITE (Chalmersite)

	1	2	3	4	5	6	7
Cu	22.88	22.27	23.52	23.57	24.32	22.96	23.4
Fe	41.41	43.13	41.14	41.24	41.15	42.51	41.2
S	35.35	35.11	35.30	36.00	34.37	34.78	35.4
	99.64	100.51	99.96	100.81	99.84	100.25 ^a	100.0

1. Cubanite, Frood Mine, Sudbury, Ontario; analyst, International Nickel Co., H. Waern, Chief Chemist.

2. Chalmersite, Morro Velho Mine, Minas Geraes, Brazil; analyst Florence, on 0.0896 gm. crystals. Hussak (1906).

3. Chalmersite, Threeman Mining Company, Landlocked Bay, Prince William Sound, Alaska; analyst Allen. Johnson (1917).

4. Chalmersite, Tunaberg, Sweden; analyst Kalb and Bendig (1923).

5. Cubanite, Barracanao, Cuba; analyst Schneider (1895).

6. Cubanite, Cuba (Breithaupt's original material); analyst Schneidhauer (1845).

7. CuFe_2S_3 .

^a Incl. Pb, trace.

The new analysis agrees closely with previous analyses of materials from the type locality in Cuba, and from Sweden, Alaska and Brazil; and all the analyses compare well with the now accepted formula CuFe_2S_3 . There thus remains no doubt as to the identity of well-described minerals named cubanite or chalmersite. One uncertainty, however, still remains. In Dana (1892, p. 79) there are four early analyses (1, 2, 3, 5 Dana's numbers) of a massive mineral from Cuba which accord much more nearly to the formula CuFe_2S_4 , which was once ac-

cepted both for cubanite and for chalmersite.² In the absence of any descriptive details regarding the analyzed materials, and in view of the fact that none of the modern analyses comes close to the composition CuFe_2S_4 , one may justly suspect the purity of the analyzed substances. If, however, further work should confirm the existence of an individual mineral with the composition CuFe_2S_4 , it would be proper to follow Schneider (1895) and Doelter (1925) and name it barracanite.

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² By a curious error, Dana (1892, p. 79) gives the percentage proportions actually corresponding to CuFe_2S_3 as those for CuFe_2S_4 .

GANOPHYLLITE AND ZINCIAN AMPHIBOLE FROM FRANKLIN FURNACE, NEW JERSEY.*

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GANOPHYLLITE

INTRODUCTION

The mineral ganophyllite was first described by Axel Hamberg¹ from Pajsberg, Sweden, associated with caryopilite, barite, lead, rhodonite, calcite, garnet, manganophyllite and pyrophanite.

Later small needle-like crystals associated with rhodonite and axinite from Franklin Furnace were investigated by Esper S. Larsen and Earl V. Shannon² who showed that these crystals were identical with the Swedish ganophyllite. This mineral had previously been listed as occurring at Franklin Furnace by Charles Palache.³ The mineral has also been reported by A. F. Rogers from a large boulder of manganese ore at San Jose, California. Rogers' determination, however, was based on a comparison of optical data with those given for ganophyllite by Hamberg, but now shown by Larsen⁴ to be much in error.

Some time ago Mr. R. B. Gage of Trenton, New Jersey, brought the writer several specimens of a very coarse platy brown mineral (U. S. N. M. No. R-6724, C-5096, C-5097) found on the picking belt at the zinc mine at Franklin. This material resembles a coarse form of ferroschallerite and was at first believed to be that mineral. Optical examination, however, showed it to be distinct from ferroschallerite and chemical examination revealed the mineral as ganophyllite.

CHEMICAL PROPERTIES

Abundant pure material in the form of a clear brown cleavage plates was available for chemical investigation.

The analysis carried out by standard methods gave the results given below. With this are given the results of Hamberg's analysis on the Pajsberg mineral. The analysis of the Franklin ganophyllite by E. V. Shannon⁵ was unfortunately made on a sample weighing but .0735 gram and cannot, therefore, be considered as of more than determinative value.

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¹ *Geol. Fören. Förhandl.*, vol. 12, pp. 586-598, 1890.

² *Am. Mineral.*, vol. 9, pp. 238-240, 1924.

³ *Am. Jour. Sci.*, vol. 29, p. 187, 1910.

⁴ *Op. cit.*, p. 239.

⁵ *Op. cit.*, p. 239.

ANALYSES OF GANOPHYLLITE

	I	II
SiO ₂	44.36	39.67
Al ₂ O ₃	11.40	7.95
Fe ₂ O ₃	None	0.90
FeO	0.09	—
CaO	2.64	1.11
MgO	3.82	0.20
MnO	24.24	33.15
Na ₂ O	2.86	2.18
K ₂ O	0.26	2.70
H ₂ O	10.72	9.79
PbO?	—	0.20
	<hr/> 100.39	<hr/> 97.85

I Ganophyllite. Franklin (U. S. N. M. No. R-6724) New Jersey. W. F. Foshag, *analyst*.

II Ganophyllite. Pajsberg, Sweden. A. Hamberg, *analyst*.

From the results on the Franklin mineral the formula derived is approximately (5Mn,Mg,Ca,Na₂,K₂,Fe)O·Al₂O₃·7SiO·5H₂O. It is evident, however, from a comparison of the two analyses that ganophyllite is quite variable in its composition.

Ganophyllite is decomposed by dilute hydrochloric acid with separation of skeletons of silica. Before the blowpipe the mineral turns pale brown and fuses quietly to a pale brown bead. In the closed tube it gives off water and becomes shiny black.

PHYSICAL AND OPTICAL PROPERTIES

The color when fresh is a light cinnamon brown but on exposure it gradually darkens to an almost biotite black. The freshest thin cleavages are very pale hair brown, almost colorless. Oxidation clouds and darkens the color. The luster is pearly on the cleavage face and vitreous to somewhat resinous across the cleavage.

Under the microscope ganophyllite is biaxial, negative, with a medium axial angle. $\alpha=1.545$, $\beta=1.586$, $\gamma=1.589$. Dispersion moderate, r less than v . Plane of the optic axes and the acute bisectrix are normal to the cleavage.

Cleavage micaceous, perfect. Hd. $3\frac{1}{2}$. G. 2.878. Very brittle.

OCCURRENCE

The association of this ganophyllite is totally dissimilar from that previously reported. In these specimens the ganophyllite occurs in large masses as much as four centimeters across showing perfect cleavage. It is associated with coarse gray massive quartz, coarse pink feldspar and deep greenish black cleavages of soda amphibole (U. S. N. M. No. C-5097); or as broad cleavage masses with cleavages of amphibole in

calcite and barite (U. S. N. M. No. R-6724). The specimens suggest that the ganophyllite occurs in calcite at or near its contact with pegmatite.

A third form of Franklin ganophyllite is to be noted: In veins in franklinite ore, eight millimeters across made up of reticulated rods with longitudinal cleavage (U. S. N. M. No. 97499). Associated with the ganophyllite in these veins are a few rod-like crystals of pale green willemite.

RELATIONSHIP

The chemical formula usually assigned to the Swedish ganophyllite is $7\text{MnO} \cdot \text{Al}_2\text{O}_3 \cdot 8\text{SiO}_2 \cdot 6\text{H}_2\text{O}$. The Franklin mineral is approximately $5\text{MnO} \cdot \text{Al}_2\text{O}_3 \cdot 7\text{SiO}_2 \cdot 5\text{H}_2\text{O}$. It is evident that the chemical composition of ganophyllite is variable.

Ganophyllite has been classed in the zeolitic division, largely on the basis of its low alumina content and the zeolitic behavior of its water. Its platy habit and brittle nature suggest a chloritic or brittle mica mineral and it is, in fact, entirely analogous to some of the leptochlorites, particularly stilpnomelane. Below is a comparison of the Franklin and Swedish ganophyllite with stilpnomelane from Lane's quarry, Westfield, Connecticut, as well as with the Swedish mineral ekmannite.

MOLECULAR RATIOS OF GANOPHYLLITE, STILPNOMELANE AND EKMANNITE

	I	II	III	IV
SiO ₂	.7386	.6612	.7310	.6683
Al ₂ O ₃	.1115	.0772	.0464	.0497
Fe ₂ O ₃	—	.0056	.0334	.0225
FeO	.0012	—	.3244	.3559
CaO	.0471	.0198	—	—
MgO	.0947	.0050	.2073	.1895
MnO	.3418	.4950	.0123	.1005
Na ₂ O	.0461	.0352	—	—
K ₂ O	.0028	.0287	—	—
H ₂ O	.5950	.5439	.6930	.5961

I Franklin, N. J. Col. I. Table 1.

II Pajsberg, Sweden. Col. II. Table 1.

III Stilpnomelane. E. V. Shannon, *Proc. U. S. Nat. Mus.*, vol. 57, p. 400, 1920.^a

IV Ekmannite, Grythyttte, Sweden. Anal. No. 3, *Dana*, p. 662.

^a SiO₂ 44.08; Al₂O₃ 4.74; Fe₂O₃ 5.27; FeO 23.31; MgO 8.36; CaO tr.; MnO .87; H₂O 12.49.

Combining these ratios we have the following relationships between these four minerals.

	(R ₁ R ₂)O	R ₂ O ₃	SiO ₂	H ₂ O
Ganophyllite No. 1	.5537	.1115	.7306	.5950
Ganophyllite No. 2	.5337	.0323	.6612	.5439
Stilpnomelane No. 3	.5440	.0798	.7310	.6930
Ekmannite No. 4	.6459	.0722	.6683	.5961

It is evident from this table that the two ganophyllite ratios agree as well with those of stilpnomelane and ekmannite as they do with each other. These minerals are variable in composition and probably represent members of an isomorphous series in which ganophyllite is a manganese member; stilpnomelane an iron member and ekmannite an intermediate member.

Ganophyllite shows some resemblance to manganophyllite but has less alumina and less alkalis. The Pajsberg mineral shows a somewhat closer relationship to manganophyllite than does the Franklin ganophyllite.

ZINCIAN AMPHIBOLE

GENERAL

The amphibole associated with the ganophyllite resembles ordinary hornblende but an optical examination suggested a sodic amphibole near riebeckite. An analysis shows this mineral to be a zincian sodic amphibole. This amphibole is intimately associated with the ganophyllite, occurring as prismatic crystals of a dark green to black color in ganophyllite, quartz or calcite. The largest crystal is four centimeters long and one centimeter broad. The crystals show a round outline but without definite terminations. The cleavage angle ($m \wedge m$) is $124^{\circ} 13'$.

CHEMICAL PROPERTIES

An analysis of the pure mineral gave the following results:

ANALYSIS OF ZINCIAN AMPHIBOLE, FRANKLIN, N. J. (U. S. N. M. No. C-5097)
W. F. Foshag, analyst

	Per cent		Per cent
SiO ₂	53.20	ZnO	4.70
TiO ₂	0.12	MnO	2.97
Al ₂ O ₃	5.37	CaO	3.36
Fe ₂ O ₃	8.03	Na ₂ O	4.35
FeO	4.46	K ₂ O	0.21
MgO	11.12	H ₂ O	1.79
			Sum 99.63

The amphibole, therefore, is not an ordinary amphibole but shows an unusual amount of zinc and manganese. Harry Berman and E. S. Larsen⁶ have proposed as the general formula of the alkali amphiboles the following: $(\text{Ca}, \text{Na})_2 \text{Na}_{0-1} \text{Mg}(\text{Mg}, \text{Al})_4 (\text{Al}, \text{Si})_2 \text{Si}_6 \text{O}_{22} (\text{O}, \text{OH}, \text{F})_2$. This is a modification of the general formulas proposed by W. Kunitz⁷ and B. E. Warren.⁸

With these formulas the analysis of the Franklin mineral agrees reasonably well as the following ratios show:

RATIOS OF ZINCIAN AMPHIBOLE

Si	.8823	.8823	$8 \times .1104$
Ti	.0015		
Al	.1050	.2071	$2 \times .1035$
Fe'''	.1006		
Fe''	.0621	.3379	$3 \times .1129$
Mg	.2758		
Zn	.0577		
Mn	.0419		
Ca	.0599	.3043	$3 \times .1014$
Na	.1404		
K	.0044		
(O, OH)	2.7452	2.7452	$24 \times .1131$

The formula for the Franklin mineral may then be written as follows: $(\text{Na}, \text{Ca}, \text{Zn}, \text{Mn})_3 (\text{Mg}, \text{Fe}'')_3 (\text{Al}, \text{Fe}''')_2 \text{Si}_6 \text{O}_{22} (\text{O}, \text{OH})_2$.

PHYSICAL AND OPTICAL PROPERTIES

The color of the Franklin amphibole is that of ordinary hornblende, a dark greenish black. The pleochroism, as is given below, is that of the sodic amphiboles. The mineral is biaxial, negative, with a medium large axial angle. Dispersion strong, r less than v . $\alpha = 1.665$; olive green; 28° to c . $\beta = 1.673$; dark sage green. $\gamma = 1.676$; dark olive green = b .

OCCURRENCE

Like the ganophyllite, the amphibole occurs both in the calcite-barite matrix and in the quartz-feldspar matrix. To judge from its chemical composition and relationship the amphibole and ganophyllite are both of the same period of mineralization.

⁶ *Am. Mineral.*, vol. 16, pp. 140-144, 1931.

⁷ *Neues Jahrb. Min., Beil. Bd.*, Abt. A, 60, pp. 171-250, 1929.

⁸ *Zeit. Krist.*, vol. 72, pp. 493-517, 1930.

NOTES AND NEWS

ORIENTATION OF MINERALS IN "AUTOLITHS"

ADOLF PABST, *University of California, Berkeley, California.*

I have read with great interest the paper by Cornelius S. Hurlbut, Jr., on dark inclusions in a tonalite from Southern California¹ and welcome especially the report of orientation measurements. It is to be hoped that Dr. Hurlbut will soon give us further reports on this work.

About eight years ago. I made some observations on the orientation of minerals in the inclusions in the granitic rocks of the Sierra Nevada. Those observations, made without a universal stage, suggested to me the parallel orientation of minerals in inclusion and host rock which has now been described by Dr. Hurlbut.

A few years ago when a universal stage became available to me, I collected oriented specimens of granitic rocks and inclusions at 9 different localities in the Sierra Nevada; and had prepared from them 25 large oriented thin-sections. To date I have measured 500 plagioclase grains and an equal number of quartz grains in three of these sections. I had intended to make several thousands of measurements, but since the results have been partly anticipated by Dr. Hurlbut, I shall not continue the work.

My measurements show that the (010) faces of the plagioclase of both inclusions and host rock tend to lie parallel to the "direction of streaking" and that the quartz lacks orientation, just as found by Dr. Hurlbut. The orientation of the *a*-axes of plagioclase reported by Dr. Hurlbut is not found in my material, perhaps because of a difference of habit of the feldspars.

It seems certain that the minerals of the "autoliths" must have been subject to the same orienting forces as the minerals of the enclosing rock. The material of the "autoliths" seems still to have been in a sufficiently plastic state for them to be shaped and their minerals to be oriented after they had become separate units within the host rock. Dr. Hurlbut is to be congratulated on having been able to trace the connection of an earlier basic rock with the dark inclusions. I have looked in vain for just this sort of relation in scores of places in the Sierra Nevada.

¹ *Am. Mineral.*, vol. 20, pp. 609-630, 1935.

ANDALUSITE IN PEGMATITE

JOSEPH MURDOCH, *University of California at Los Angeles.*

In several pegmatite dikes cutting across the magnesite deposits at Winchester, California (described by Gale and Hess),¹ the writer ob-

¹ Hess, F. L., *U. S. Geol. Survey, Bull.* 355, pp. 38-39.

Gale, H. S., *U. S. Geol. Survey, Bull.* 540, p. 516.

served a reddish brown mineral which proved on investigation to be andalusite. Since andalusite is not a common constituent of pegmatites, the occurrence seems worthy of mention and a brief description.

The country rock is a metamorphosed sedimentary series, now a schist, intruded by peridotite, and the whole mass is cut by a number of small pegmatite dikes. The peridotite is almost completely altered to serpentine, with veins of magnesite, while the pegmatites are essentially unaltered. Andalusite occurs in two distinct types of dikes, one dark in color, the other light.

The dark pegmatite is well exposed in one of the quarry pits, and shows clean cut, regular walls against the serpentine. The component minerals are, roughly in order of abundance, as follows: a dirty white to gray plagioclase feldspar, white orthoclase, quartz, black tourmaline, andalusite, biotite, sillimanite, and exceptionally, a grain or two of bright blue cordierite. The gray plagioclase is oligoclase ($Ab_8 An_2$), frequently filled with poikilitic blebs of quartz. The orthoclase is entirely free from quartz, and occurs in scattered, rather large individuals. Quartz also occurs interstitially to the feldspars. Andalusite appears as square prisms from an eighth to half an inch across, by one to three inches long, or in more irregular masses of varying size. Most of it is nearly opaque, but occasionally the interior of a prism may be perfectly transparent, reddish, green, or even colorless. Andalusite tends to be concentrated along the borders of this dike, with a little perhaps even in the wall rock. Close examination shows the presence of sillimanite more or less completely replacing some of the andalusite grains. Thin sections further confirm this relationship, and show the strong pleochroism of the andalusite, pink to colorless.

While the gray feldspar is dominantly oligoclase, one nearby portion of this dike carries a blue gray, much darker feldspar, and black tourmaline, but no andalusite. This feldspar is andesine (about $Ab_3 An_6$), which shows both albite and pericline twinning, sometimes in "checker-board" structure.

In the light colored pegmatite the grain is rather fine, and the mineral association is albite and quartz, in about equal proportions, rather evenly distributed andalusite, and a very small amount of black tourmaline. The andalusite in this locality tends to be paler in color than that in the dark colored dike.

BUSTAMITE FROM INYO COUNTY, CALIFORNIA

JOSEPH MURDOCH AND ROBERT W. WEBB, *University of California at Los Angeles.*

In the course of field work in Saline Valley, Inyo County, California, numerous boulders of a silicate rock containing large irregular patches

of a pink mineral were collected in a large alluvial fan on the east side of the valley near the south end. The mineral proved upon examination to be bustamite.

Qualitative tests indicate: (1) manganese, strong test with borax bead; (2) magnesium, small amount when precipitated as magnesium ammonium phosphate; (3) presence of iron; (4) presence of calcium. Physical properties are: hardness, 5.5–6.5; cleavages, two directions, one prominent, one imperfect; color, brilliant pink to rose; luster, vitreous to pearly. The beta index was determined as 1.70.

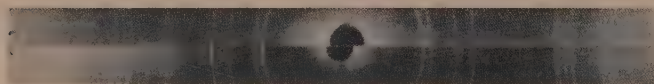
The source of the boulders could not be located. This is the first occurrence of this member of the rhodonite series known to the authors in the State of California.

THE PROBABLE NON-EXISTENCE OF ARSENOFERRITE

M. J. BUEGER, *Massachusetts Institute of Technology, Cambridge, Mass.*

Foshag and Short¹ have described some apparently isotropic metallic mineral of analysis close to ideal FeAs_2 . They suggested that this mineral might be the iron arsenide member of the pyrite group.

From certain crystal structural considerations it seemed to the writer unlikely that FeAs_2 would assume the pyrite type of structure, and that this isotropic material, therefore, represented some other crystal structure type. Dr. Foshag was kind enough to supply some coarse powder from the original analyzed arsenoferrite for x -ray examination. Powder photographs were taken of this material using cobalt radiation (which is only slightly absorbed by iron-bearing minerals).



ARSENOFERRITE

LÖLLINGITE

FIG. 1

It quickly became apparent that it was impossible to reconcile the arsenoferrite diffraction pattern with that to be expected from a crystal based on any of the cubic space lattices. Since the mineral is not cubic, the possibility therefore suggested itself that it is löllingite. That this is indeed the case is proved by a comparison of the powder photograph of arsenoferrite with that of löllingite from Reichenstein, Germany. Figure 1 clearly indicates that these two materials are identical, except that the arsenoferrite has slightly greater interplanar spacings.

¹ Foshag, William F., and Short, M. N., Arsenoferrite from Jachymov, Czechoslovakia: *Am. Mineral.*, vol. 15, pp. 428–439, 1930.

It remains to reconcile Short's determination of optical isotropism with a non-cubic diffraction pattern and specifically with the known rather strong anisotropism of löllingite (clearly evident in a polished section of the Reichenstein löllingite check). While the writer did not examine polished sections of Foshag and Short's arsenoferrite, a binocular examination of the coarse powder at his disposal indicated an extremely fine grain. The material has an appearance suggesting broken porcelain. There is x -ray evidence to the effect that the material is indeed extremely fine, for the high θ lines on the powder photograph are relatively weak, and the doublets in this region are unresolved. If sufficiently fine grained, the material would appear isotropic in aggregate, although the individual crystals would be anisotropic.

Since Foshag and Short's evidence for the existence of Baumhauer's² hypothetical "arsenoferrite" was the only direct evidence extant, it seems desirable to discontinue the use of the term.

² Baumhauer, H., Arsenoferrit, ein neues Glied der Pyritgruppe: *Zeit. Krist.*, vol. 51, pp. 143-145, 1912.

CORRECTIONS

X-RAY POWDER DIFFRACTION DATA FOR ANTLERITE AND BROCHANTITE

A. W. WALDO, *The Pennsylvania State College,
State College, Pennsylvania.*

Dr. George Tunell of the Geophysical Laboratory has kindly brought to my attention the fact that incorrectly identified material was used in securing the x -ray data erroneously called antlerite in my paper entitled "Identification of the copper ore minerals by means of x -ray powder diffraction patterns"; this Journal, August issue, 1935. By means of optical methods I have checked the supposed antlerite that I used, and find it to be brochantite. I also find that the data obtained from this specimen of brochantite check the original data of Posnjak and Tunell (*Am. Jour. Sci.*, vol. 18, pp. 12-24, 1929) better than the brochantite record published in my article cited above. For purposes of comparison I am listing the three records for brochantite in Table 1.

X -ray powder diffraction data from analyzed artificial crystals of antlerite the three refractive indices of which were measured, as well as other optical properties, and on which angular measurements were also made, were published by Posnjak and Tunell (*Am. Jour. Sci.*, vol. 18, pp. 12-24, 1929). Dr. Tunell has pointed out also that more complete data for the x -ray diffraction pattern of tenorite have recently been published by Tunell, Posnjak, and Ksanda (*Zeit. Krist.*, vol. 90, pp. 138-139, 1935).

TABLE 1

Posnjak and Tunell		Waldo			
Brochantite		Supposed Antlerite; really Brochantite		Brochantite	
Spacing	Intens.	Spacing	Intens.	Spacing	Intens.
6.20Å	7	This line not registered on cassettes used			
5.25	7			5.35Å	m
3.83	9	3.85Å	s	3.91	s
3.14	4	3.17	w	3.20	m
2.88	2	2.90	ew	2.93	w
		2.80	ew	2.82	ew
2.65	7	2.66	m	2.63	m
2.58	1			2.60	vw
2.49	10	2.51	s	2.52	s
2.44	1	2.45	m	2.47	m
2.36	1	2.37	vw	2.39	w
				2.30	vw
2.26	2			2.27	vw
2.17	3	2.18	w	2.19	m
2.12	1	2.13	w	2.14	w
2.06	2	2.07	ew	2.08	w
2.00	1	2.00	ew	2.01	vw
1.95	2	1.949	ew	1.965	w
				1.918	vw
1.88	1			1.885	vw
1.81	1	1.810	w	1.822	w
				1.787	w
1.73	5	1.733	m	1.740	m
1.70	1	1.701	ew	1.712	w
1.66	1	1.663	ew	1.675	w
1.62	2	1.628	vw	1.635	w
1.59	1	1.591	vw	1.595	w
1.56	2	1.558	w	1.563	m
1.53	2	1.532	w	1.537	m
1.50	3	1.500	w	1.505	m
1.46	1	1.454	ew	1.463	w
1.42	1	1.425	ew	1.434	w
1.39	2	1.400	ew	1.405	w
1.33	1	1.337	ew	1.338	w
1.31	2	1.311	ew	1.312	w
1.28	1	1.260	ew	1.282	w
				1.093	ew
				1.077	ew
				1.058	ew
				1.015	ew
				1.000	ew
				0.904	ew
				0.819	ew

I also desire to record here as applying to my results, that with molybdenum radiation, which was employed throughout my work, and with the cassettes which I used, diffraction lines corresponding to spacings greater than 6.0 Å could not be obtained.

ANALYSES OF THULITE

STUART A. NORTHROP, *University of New Mexico.*

In an article in the November 1935 issue of this Journal the writer reported that he had found only one other analysis of thulite (from Norway).¹ He has recently discovered an analysis, made by L. G. Eakins,² of material recorded not as thulite but as "rose-red zoisite," from James's mica mine, Yancey County, North Carolina. The specific gravity of the North Carolina material is much higher than the average (North Carolina 3.352; Connecticut 3.19; New Mexico 3.15; Norway 3.124).

The analysis of the North Carolina material follows: SiO₂ 38.98; Al₂O₃ 31.02; Fe₂O₃ 4.15; CaO 23.80; MnO 0.23; H₂O 2.03; total 100.21. The silica here is much lower, and the lime much higher, than in either the Norway or New Mexico material. Manganese was not reported in the Norway material but was given in that from both North Carolina and New Mexico.

¹ Northrop, Stuart A., Thulite in New Mexico: *Am. Mineral.*, vol. 20, p. 807, 1935.

² Clarke, F. W., *U. S. Geol. Survey, Bull.* 220, p. 49, analysis B, 1903.

NOTICE

Report of the Committee on the Measurement of Geologic Time.

Professor Alfred C. Lane, Chairman of the Committee on the Measurement of Geologic Time, announces that the report for 1935 is ready for distribution and will be sent without charge to those interested in the work and able to assist through the furnishing of information or specimens.

Requests for the report should be addressed to the Division of Geology and Geography, National Research Council, 2101 Constitution Ave., Washington, D. C., and inquiries regarding the work of the Committee to Professor Alfred C. Lane, Barnum Museum, Tufts College, Medford, Massachusetts.

BOOK REVIEW

THE BOOK OF MINERALS. ALFRED C. HAWKINS. 161+XII pages, 5 plates and 62 figures. John Wiley & Sons, Inc., New York, 1935. Price \$1.50.

In the preparation of this book of 161 pages the author had in mind the average mineral collector and layman whose technical knowledge of the basic sciences is limited and therefore unable to read profitably the usual mineralogical texts used in class room instruction. The result is a very readable, largely descriptive booklet, liberally illustrated containing the essential characteristics of the more common minerals.

The treatment of crystal forms (crystallography) and the chemical tests employed for the determination of minerals (blowpipe analysis) have been largely dispensed with and the space devoted instead to such general topics as where to collect minerals, how to collect them, how to preserve them if unstable and the types of minerals one might expect to find in quarries of limestone, marble, sandstone, granite, schist and gneiss, serpentine, shale and slate. A bibliography of 26 entries calls attention to some of the more comprehensive texts on the subject and journals carrying mineralogical articles.

The descriptive portion follows the classification of minerals as given by Dana and as many museums follow the same order the text can be used to advantage as a guide in studying these collections. With the present revival of interest in minerals as revealed by the numerous mineralogical clubs holding regular meetings this handy booklet should command a ready sale.

W. F. H.

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, September 5, 1935

A stated meeting was held with Vice-president Arndt in the chair. Thirty-four members and twenty-three visitors were present.

"Reports of Summer Trips" included accounts of visits to New England by Messrs. Arndt, Morgan, and D'Ascenzo; and local trips to Franklin, N. J., the French Creek mines, and Bridgeport, Pa., by Messrs. Morgan, Moyd, Knabe, Poole, and Jehle. Specimens exhibited included lepidolite from the Greenlaw mine dumps and garnet and beryl from Topsham, Maine; babingtonite and datolite from Westfield; crocidolite from Franklin; coal from the Triassic beds at Collegeville; analcite from Rushland, Pa.; and cyanite from Washington, Conn.

MORRELL G. BIERNBAUM, *Secretary pro tem*

Academy of Natural Sciences of Philadelphia, October 3, 1935

Vice-president Arndt was in the chair at a meeting at which 46 members and 40 visitors were present.

New officers elected were, President: Harold W. Arndt; Vice-president: Harry W. Trudell; Secretary: Wylie H. Flack; Treasurer: Morrell G. Biernbaum; Councillor: Charles R. Toothaker.

Mr. Stephen Varni addressed the society on "Gems and Gem Anecdotes" illustrated with colored lantern slides and specimens.

W. H. FLACK, *Secretary*